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A Digital Simulation Model of Message Handling in the Tactical Operations System: I. The Model, its Sensitivity, and User's Manual

by

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The results of research into implementation of a quantitative model of human performance in information systems are presented. The principal efforts were to: (1) define the most influential psychosocial variables inherent in the mission of interests, (2) incorporate these into a logic for a digital simulation model, and (3) develop a computer program reflecting this model. The Tactical Operations System (TOS) for which the model was developed is described, and model features involving predictive capability and system effectiveness measurements are presented. The results of a series of model → next page

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cont.
20. sensitivity tests under a variety of parametric input conditions are reported.

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CHAPTER I

INTRODUCTION

Scope

This report presents a description of a digital computer model for simulating the actions of operational field army personnel in performance of their message processing tasks during a Tactical Operations System (TOS) mission. The basic structure of the model is developed and its logic is presented, with particular emphasis on the behavioral aspects as they impact on the human performance and as they interact with the operational and equipment system aspects of the mission.

Initial computer sensitivity runs made with the model indicate the extent of the feasibility of using this model as a predictive technique to simulate the message processing aspects of the combined man-machine system.

Following a brief review of the similar prior models upon which the TOS model is based conceptually, the remainder of Chapter I contains a general description of the TOS. The reader who is familiar with the TOS *per se* and who is interested primarily in the simulation model and its application to TOS may turn to Chapter II without depending on the material presented in the balance of this chapter.

Similar Prior Models

The work in developing the simulation for TOS relies in part on techniques and concepts previously developed by Applied Psychological Services and included in a family of three prior man-machine digital simulation models. All three of these models, now operational, have been developed to simulate one or more men operating or maintaining equipment. They are general to the extent that each one treats a task for which the action sequence can be specified in the required detail and provided as primary computer input data.

Thus, use of each model requires an analysis of the task or mission to be simulated prior to simulation. This analysis provides input data to the computer. These data, together with information on equipment, personnel, emergencies, and the like are prepared for computer processing in accordance with a program which implements the model's logic. Under program control, the computer starts at mission time zero and simulates the crew's performance of each unit of work or occurrence during the mission. The program allows simulated operators to do such things as: work independently or in groups, wait for each other, talk to each other, monitor and operate controls and displays, wait for equipment, sleep, skip less essential tasks, make decisions which can alter the task sequence, recycle if required (e.g., in the event of an operator failure), become partially or completely incapacitated, and respond to unexpected failures and emergencies. The models reward their keepers with results in the form of computer output tabulations which are reflective of the total man-machine system under study, and which are indicative of both personnel and system performance. Results include values such as personnel over or underload points, periods of unusual stress and excessive delays, distributions of how mission time is spent, a variety of end-of-mission conditions, and implications of manning strategies.

This family of models is directed towards the simulation of missions by crews in a closed environment such as a ship, airplane, or spacecraft, i.e., a situation in which the crew composition does not usually change during the mission.

These models were designed especially for use in simulating difficult or untried missions--those in which the operator's skill, physical limitations, and mental limitations may play an important part in the ability of the man-machine system to perform its function. Therefore, in their development, emphasis was placed on human or operator-oriented variables. All three models have major simulation variables to reflect the realities of the equipment, the mission itself, and one or more functions of time. Yet, they all possess, in addition, and this represents their distinctive feature, psychological and social variables pertaining to the operator or operators. Examples of these variables are: stress, proficiency, aspiration level, mental load, and fatigue. That is, in addition to the more ordinary results such as equipment reliability, operator working hours, and operator failures which one might expect from digital computer simulation models, the models in this family generate additional data on such variables as personnel performance, morale, cohesiveness, goal orientation, and man-machine system efficiency.

Like the current model, all of these models are based on the Monte Carlo approach in which pseudo random numbers are used to sample desired statistical distributions for use during the simulation. They are also used to select alternative courses of action with predetermined probabilities. This nonanalytical approach results in approximate solutions whose accuracies are dependent on the number of samples (iterations) taken. Thus, it is assumed that a given result will have some inherent sampling inaccuracy (standard error) but that the accuracy may be improved by large numbers of simulation iterations. For a further discussion of the reasons for modeling, accuracies to be expected, conditions under which digital simulation models are reasonable, and similar introductory material, the reader is referred to Siegel and Wolf (1969).

It should be noted that a major feature of the TOS model, i. e., queuing (simulation of messages awaiting attention and their selection for processing by the system operators) is one not found in the family being described. In prior models, operators proceeded from task to task without selection of which unit of work or raw material on which to concentrate next.

All three prior models have been evaluated against data obtained empirically from actual missions. All are programmed in FORTRAN. The two principal differences between the three models are: (1) the number of operators which are simulated simultaneously, and (2) the level of detail simulated. These differences and other major features are shown in Table 1-1.

Table 1-1

Major Features of Three Prior Applied Psychological Services' Man-Machine Simulation Models

Model Name	Number of Men	Operational Date	Duration Task Element	Maximum No. of Task Elements	Nominal Computer Time Per Action (seconds)	Operator Processing
Two-man	1-2	1962	seconds or minutes	up to 300	0.003	individual
Intermediate	3-20	1970	minutes or hours	80 per day	0.020	group
Large group	20-99	1965	minutes or hours	100 per day	0.200	group

The Two-Man Model

The two-man model (the first entry) simulates one or two operators and accommodates up to 300 individual actions by each operator. Each such operator action which would require a few seconds or minutes of operator performance is simulated by the computer in about 3 milliseconds. Consequently, 100 computer iterations (simulations) of a task (300 actions for each operator) takes about two to four minutes of computer time. This model, originally developed over 12 years ago, is still in active use and is undergoing further refinement by a variety of users. Siegel and Wolf (1969) described briefly four applications of the dual operator simulation model. The first two of these applications, landing an aircraft on an aircraft carrier and launching an air to air missile, represent single operator situations. The second pair of applications, simulation of an inflight intercept of an enemy aircraft, and simulation of an inflight refueling operation, each represent two operator simulations. This simulation model can provide predictions, early in the development of a system, of the effects of such factors as operator ability (speed), operator stress tolerance, task urgency, operator level of aspiration, and interoperator experience on performance times, waiting times, failures, and the man-machine system's success probability.

The basic notions of this model (including task sequencing, operator stress, operator speed variation, etc.) were utilized in the portion of the TOS model concerned with actual operator message handling tasks once a given message has arrived and has beer selected from the queue.

The Intermediate Model

In the recently completed intermediate model, a crew of up to 20 men may be simulated. This model handles the case of multi-day missions in which times of individual events are measured in minutes or hours. This is accomplished by processing tasks performed by groups of one or more men. Here, the computer simulates each of these longer events performed by the group in about 20 milliseconds. In this case, 100 iterations of a maximum mission (80 crew events per day) for, say a five day mission, takes about 10 to 15 minutes of computer time.

This model yields such measures as performance adequacy, crew morale, stores expended, crew fatigue level, optimum manning, and stress on the crew. An actual Navy system and its crew (river patrol combat performance in Viet Nam) were used as the validational test. This model is described in Siegel, Wolf, and Fischl (1969).

A technical report describing the methods, procedures, and results of the validational effort was published by Siegel, Wolf, and Cosentino (1971), and a report on another application is in preparation.

The Large Group Model

With the large group model, the performance of a crew of from 20 up to 99 men may be simulated. The mission is composed of work units, each of which may be minutes or hours in duration, and the total mission may last for several dozen days. The computer time required for this model is heavily dependent on crew size but in general is an order of magnitude more than the intermediate. Since this model is concerned with group performance, the inputs to the model are principally concerned with group oriented variables salient to behavior. In this model, variables such as group and crew morale and cohesiveness, operator orientation, proficiency, performance time, overtime, communications, sickness and system effectiveness are computed.

The simulation itself involves the numerical prediction of performance for individualized "men" selected from the computer generated "crew" to form small "groups" which "accomplish" each specific task of the mission. The Monte Carlo approach is used for incorporation of equipment failures and repair, as well as for crew sickness and emergencies. Random number generation and utilization is accomplished for rectangular, normal, and Poisson distributions.

The conceptual system, psychological, and mathematical analysis for this model were completed by Applied Psychological Services, and the initial model was described in Siegel, Wolf, Barcik, and Miehle (1964). Following program and model sensitivity testing, a revised model description was published (Siegel & Wolf, 1965). This report contained an overview of the model itself, descriptive information on the program, and discussion of changes and corrections to the theoretical bases for the model which appeared in the first report. Results of the ten-day mission simulation were also presented.

In 1966, Applied Psychological Services began a program of the operational validation of this model. Using data from underseas craft of the 627 class of submarines, numerous computer simulations of a 21-day mission were made with crew sizes varying from 48 to 61. The results of the validational effort are reported in Siegel, Wolf, and Lanterman (1967).

TOS Description

The TOS has been described as follows:

> The Tactical Operations System (TOS) is an automated secure information processing system designed to assist military commanders and their staffs at Field Army, Corps, and Division levels in the conduct of tactical operations. To achieve its purpose, TOS provides a central repository of information into which remote users can enter data, update the data as required, have the data processed, and, as an end result, be provided with up-to-date dynamic information which can be used as a basis for tactical decisions by commanders concerned.

The system's purposes--assisting commanders in the conduct of tactical operations--is achieved through the functioning of a complex man-equipment system.

The equipment complement consists of three equipment types --the Central Computing Center (CCC), the Remote Station Data Terminals (RSDT), and the User Input/Output Devices (UIOD). The interrelation of these units is shown in Figure 1-1, which is taken from Baker (1970a).

The Central Computing Center controls information storage and distribution according to the guidelines programmed into it.

The Remote Station Data Terminals perform intermediate functions in the transmittal of information between the UIOD and the CCC.

The operations part of the system, from a human factors point of view, is performed at one or more UIOD's. The UIOD provides for all actual information input and output. Information is handled in the form of messages.

The personnel required by the system include various maintenance personnel, as well as operations personnel who are directly involved with the information flow within the system. This study and the resulting simulation model were concerned only with operations personnel. The operations personnel are the action officers who compose and format messages and authorize them for transmittal by the UIOD operator(s). A unique system feature is the control of both input and output by the user. The action officer of each element is responsible for ensuring the most current tactical information concerning his area into the data base. In exchange, he may gain information from the updated data base in hard-copy form. The UIOD operators enter information into the system through use of a desktop typewriter, keyboard, and cathode ray tube display device. The display unit and keyboard are used primarily to transcribe and transmit messages; the typewriter is used to print messages and other data coming from the computer.

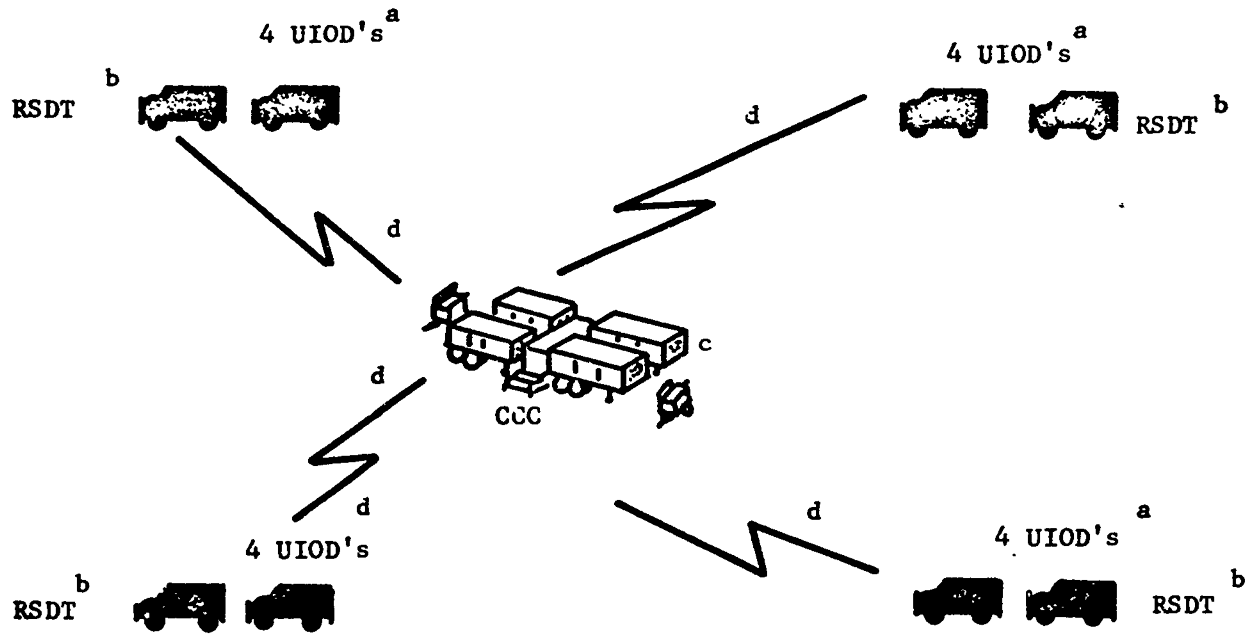

Figure 1-1. Configuration for first increment of transportable hardware for the Seventh Army TOS.

In operation, input messages are first transformed onto one of many types of message work sheets by the action officer, and then transcribed via the keyboard to similarly selected formats displayed directly on the face of the TV-like display screen of the UIOD. Using the keyboard, the UIOD operator types a three-letter code for the required format, which appears on the screen, and then transposes the variable data from the worksheet to the blank spaces on the screen format. Following display, the message is verified for correctness and entered into the system by means of a "Send" key on the keyboard. From the UIOD, the message is transmitted by cable to the nearby RSDT, and from there by a secure tactical communication link to the CCC. Information which emanates from the CCC to field locations follows a reverse procedure.

The system, as presently used, recognizes seven types of messages--add, change, delete, query, relay, special process request (SPR), and standing request for information (SRI). Different formats are required for each message type as well as for different functional areas within types.

The purpose of the add, change, and delete message types is to add to, change, or delete information presently stored in the CCC data base, e.g., task force data.

The query message type provides for the request for information from the data store.

The relay message type provides for lateral (from one UIOD to another) transfer of information in a basically free text conversational manner. The system input restrictions are thus minimal on this message type. The limitation of this message type, however, is that the information as transmitted is not available to the information data base and is inaccessible to other potential users.

The SPR type of message is similar to the query message type in that information is requested from the system. However, this message type extends the basic query capability to include the availability of specific data base savings and information summaries of various types.

The final message type, the SRI, enables TOS users to request continuing receipt of all data messages pertaining to a particular subject or area for a finite or indefinite time period, e.g., Nuclear Fire Mission SRI Establish message.

Messages output to the user by the system include: (1) messages which state that requested information is not available, (2) notices of errors, and (3) restriction-type notices, which disseminate information based on security, need-to-know, and command prerogatives. Fixed-format System Control and Fixed-text Relay messages from the system or its operators advise users of system status.

It is noted that the TOS as an effective military tool is still evolving, with many details of message formats, information categorization, and equipment response still in a state of evaluation and system improvement resulting from field tests. This makes computer simulation especially important, since computer simulation is an economical way to investigate the effects of changes on mission performance.

CHAPTER II

THE TOS MODEL

Scope

Following a summary description of the overall simulation model features, Chapter II describes the more detailed functions and characteristics of the TOS model input data, processing methods, functional relationships, and logic of the main simulation program and the principal subroutines. It also presents model inputs in the form of sample formats of computer generated listings.

Implementation of this simulation model represents the results of an attempt to develop a technique which may predict man-machine system effectiveness in TOS message handling. It places greatest emphasis on the summary of man-machine performance effectiveness in the categories of processing time, accuracy, thoroughness, completeness, and responsiveness.

The present study does not attempt to duplicate in a computer model every aspect of this real life group interactive situation. Rather, its goal is to include in the model only those parameters and variables which are believed salient to first order effects on man-machine systems effectiveness, i.e., those influencing human performance in message processing tasks associated with TOS-like field army systems. These variables and parameters are identified; their interactions are defined in terms of the mathematics and logic of the model. Via program sequence, they are set into form which allows digital computer simulation. The discussion of the selected variables, such as operator speed, precision, level of aspiration, stress and fatigue, is introduced as they are encountered in the description of the pertinent model logic. Similarly, those functional characteristics of messages which are selected for incorporation into the simulation logic (including message arrival frequency, type, priority, error rate, and length) are described as they are utilized or generated within the model.

Model Overview

As a framework, we conceive of a single communication van in the TOS field army situation which is manned by a single G-3 (operations) officer, and may include one or more action officers. These men receive messages of various types which are delivered to the van at times unknown in advance of the simulation. Their function is to screen incoming messages, decide on the order in which they are to be processed, and to select the appropriate message format onto which they transform the content of each message to be entered into the TOS data bank. One class of simulated messages is "generated" by the TOS model at random times. The other class involves situation reports which are assumed to arrive only during the last quarter of a given hour. To further process these prepared messages, the performance of one or more UIOD operators is simulated. Working from a queue of such message forms prepared by the officers, the UIOD operators transcribe the message using a keyboard and CRT edit/verify device. The purpose of the model is to simulate these personnel on an hour-by-hour basis over a single work shift consisting of an integral number of one hour time segments.

Although the above general task assignment to operators and the sequencing thereof is the current approacn, the TOS model treats these as soft. Since they are controlled by input data, they may be readily changed.

Figure 2-1 presents the summary flow logic sequencing of the model. The computer program written in the FORTRAN IV language for the CDC 3300 computer implements this flow chart and its sequenced logic as described. To facilitate both descriptive and analytic program-to-model interaction, this report utilizes the FORTRAN variable names. Appendix A presents the principal FORTRAN variable names, together with a brief description, the principal model subscripts, and the various types of input data. Subscript indices are indicated throughout by parentheses.

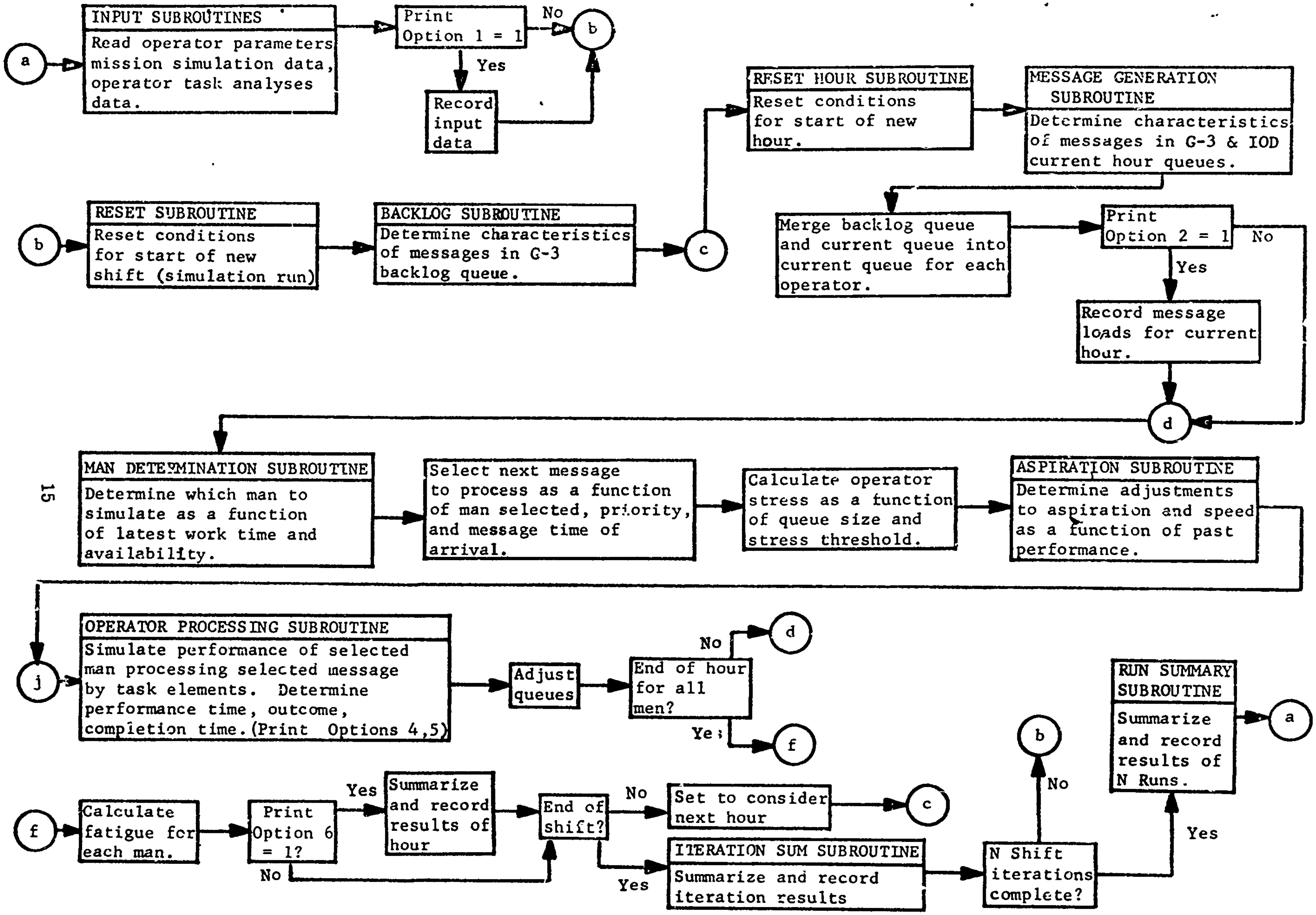

FIGURE 2-1 SUMMARY TOS MODEL FLOW LOGIC

The first table of Appendix A showing the major model subscripts serves to set the scope and limits of the simulation itself. It indicates a capacity to simulate missions up to one shift of 12 hours (IHMAX). Each shift constitutes a computer run of NSHIFT iterations. There are up to four sequences of tasks elements provided to represent the tasks executed by an operator in performing his task. Each sequence has the capacity of up to 20 task elements. The model handles up to 6 men of 2 types (any combination of G-3's and UIOD operators), 4 types of operator errors, 7 types of messages, and 4 message priority classifications.

Figure 2-1 also shows the subroutines and their interrelation with the main processing flow. An itemization of all subroutines and their functions is given in Appendix Table A-11.

Processing Sequence

Following data read-in, there is an optional recording of the input data. Conditions are then reset (circle b of Figure 2-1) for the start of simulation for a new TOS shift. The backlog subroutine (BAKLOG) generates data representing messages in the action officer's "in-box" at the start of each iteration. At circle c of Figure 2-1, following reset of counters and registers for record keeping of hourly results, the message generation subroutine (MESGEN) develops data representing messages which will arrive during the coming hour. These are merged with the backlog in order by time of arrival, and the contents of this hourly message queue is optionally recorded. At circle d of Figure 2-1, the processing of each message in turn by a single operator (either G-3, Action officer, or UIOD operator) begins. The Man Determination Subroutine (MANDET) selects the appropriate man to simulate next, and determines the next available appropriate message for this selected man to process. The operator stress and aspiration conditions applicable to that operator message situation are calculated next. At this point (circle j), all data are available for the detailed task element-by-task element simulation for the message and operator selected. This is accomplished by the Operator Processing Subroutine (PROC), which manipulates mission task analysis data in a way very similar to that used in the two-man model described in Chapter I. During this subroutine, the detailed results of the simulation of the performance of each task element, as well as the summary results for this one message, may be optionally recorded for printing.

Following this, queues are adjusted and the cycle repeats back to circle d for processing of all messages which can be handled before the next one hour segment is completed. When the end of an hour condition is reached for all men, the results of the hour's simulated activity are optionally printed. The process of simulating in one hour segments is repeated (back to circle c) until the simulation of one iteration of an entire shift is completed. When a shift iteration is finished, the iteration summary (ITSUM) subroutine generates summary data over the shift which is then printed to complete each of NSHIFT iterations. The process is repeated (back to circle b) for each iteration and after all NSHIFT iterations are complete, the run summary subroutine (RUNSUM) summarizes and records all the pertinent performance figures to complete a simulation run. Multiple runs are processed sequentially through the entire process by returning to the Input Subroutines at circle a of Figure 2-1, and processing as many sets of input data as are provided as input.

Input Data Required

The specific items of input data to be read under control of the Input Subroutines are organized into a series of data sets. Read in of these is called for at the start of each simulation run in the sequence listed in Table A-2 (Appendix). The description of each item of data required as input together with the FORTRAN name is given in Tables A-3 through A-9. These include:

	Description	Table
•	mission and simulation parameters	A-3
•	operator parameters	A-4
•	hour parameters	A-5
•	operator and message error data	A-6
•	message length data	A-7
•	operator task analysis data	A-8
•	effectiveness components	A-9

Separate data sets were specified in designing the model to facilitate the mission analyst's (model user) making a variety of simulation runs by selection of appropriate data input cards for variation.

Figures 2-2 and 2-3 present sample printouts from the model of input data available by setting the first Output Recording Option, ORO (1), equal to 1.

Model Logic Details

In describing the details of the model sequencing and logic, reference will be made to the logic flow diagram in Appendix B:

Description	Figure
Main sequence	B-1
Operator processing	B-2
Message generation	B-3
Man determination	B-4

In these charts, the circled letters correspond to those in Figure 2-1.

At circle b, the RESET subroutine is called to initialize conditions required for each shift simulation iteration. It resets the model to consider the first hour, starts counting messages, resets all times to zero, and clears message queues and counters. In the absence of data on the performance of the men simulated at this point in the beginning of the run, the performance, PERF(M), for each man, is set equal to his initial aspiration value ASP(M) given as input.

DETAIL PRINTOUT FOR INSPECTION 3-19-72 APS-WRL

NO. OF SHIFT ITERATIONS	1		NO. OF SIMULATED DAY	1
NO. OF HOURS PER SHIFT	4		INITIAL BACKLOG #G3	0
NO. OF ACTION OFFICIERS	3		RANDOM NUMBER	11531571
NO. OF IOD OPERATORS	3			

PROBABILITY OF UNDETECTED ERROR IN CCC		SYSTEM RESPONSE TIME TO INQUIRY	
LOW IMPORTANCE	.050	MEAN	0
SIGNIFICANT	.130	SD	0

OPERATOR PARAMETERS

MAN	SPEED	PRECISION	STRESS THRESHOLD	ASPIRATION
AO-1	1.00	1.00	10.00	.900
AO-2	1.00	1.00	10.00	.900
-G3-	1.00	1.00	10.00	.900
IOD1	1.00	1.00	10.00	.900
IOD2	1.00	1.00	10.00	.900
IOD3	1.00	1.00	10.00	.900

HOUR PARAMETERS

	CUMULATIVE MESSAGE FREQUENCY BY TYPE								CUM. MSG FREQ. BY PRIORITY					INPUT MESSAGES FROM OUTSIDE: DELIVERIES PER HOUR		NUMBER OF MESSAGES	
HOUR	1	2	3	4	5	6	7	8	1	2	3	4	5	ROUTINE	NOT-ROUTINE	LAST 1/4 HR	ANYTIME
1	.17	.42	.50	.84	.98	.99	1.00		.70	.90	1.00	1.00	1.00	3.0	11.0	2	8
2	.17	.42	.50	.84	.98	.99	1.00		.70	.90	1.00	1.00	1.00	3.0	11.0	2	8
3	.17	.42	.50	.84	.98	.99	1.00		.70	.90	1.00	1.00	1.00	3.0	11.0	3	12
4	.17	.42	.50	.84	.98	.99	1.00		.70	.90	1.00	1.00	1.00	3.0	11.0	2	3

ERROR FREQUENCY

	MESSAGE TYPE								ERROR RETURNS	
TYPE	1	2	3	4	5	6	7	8	G3	IOD
1	9.3	7.1	2.0	2.0	4.6	2.1	14.2		.120	.013
2	5.8	4.5	1.3	1.3	3.0	1.3	9.1		.120	.013
3	9.3	7.1	2.0	2.0	4.6	2.1	14.2		.120	.013

NO. OF CHARACTERS	MESSAGE TYPE 1	2	3	4	5	6	7	8
IN COMPUTER (M)	272	236	72	300	74	100	148	
IN COMPUTER (SD)	176	153	47	195	48	65	96	

Figure 2-2. Sample recording of input data.

DETAIL PRINTOUT FOR INSPECTION 3-19-72 APS

TASK ANALYTIC DATA

TASK	ELEMENT	TYPE	CRITICAL	SEGMENT	NEXT-FAIL	NEXT-SUCC	MEAN-TIME	SIGMA	PROBABILITY	UNDETECTED-ERROR TYPE	UNDETECTED-ERROR PROB	OPERATOR TASK ACTION
1												TASK ANALYSIS I
	1	1			2	2	8.00	2.00	.990		0	Scan messages
	2				2	3	5.00	1.50	.990		0	Select message
	3				3	4	20.00	3.00	.800		0	Screen for relevance
	4		C	3	4	5	15.00	4.00	.990		0	Select format
	5				5	6	12.00	2.50	.900		0	Locate worksheet
	6				6	7	12.00	2.50	.900		0	Find instructions
	7	2			8	8	.50	.01	1.000	T	.17	Compose message
	8		C		9	9	10.00	2.00	.660		0	Make corrections
	9				8	10	15.00	2.70	.800		0	Proofread verify
	10		C	4	10	0	20.00	10.00	.990		0	Route to UIOD
2												TASK ANALYSIS II
	1		C	3	1	2	15.00	4.00	.990		0	Select format
	2				2	3	12.00	2.50	.900		0	Locate worksheet
	3				3	4	12.00	2.50	.900		0	Find instructions
	4	2			5	5	.50	.01	1.000	T	.17	Compose message
	5		C		6	6	10.00	2.00	.660		0	Make corrections
	6				5	7	15.00	2.70	.800		0	Proofread verify
	7		C	4	7	0	20.00	10.00	.990		0	Route to UIOD
3												TASK ANALYSIS III
	1				1	2	7.00	1.50	.990		0	Select message
	2		C	5	2	3	5.00	1.00	.960		0	Request format
	3	4			4	4	.30	.02	1.000		0	Wait for format
	4	2			5	5	.40	.01	1.000		.01	Enter message
	5				5	6	12.00	3.00	.700		0	Edit./corr./valid.
	6		C	6	7	7	4.20	1.20	1.000		0	Send message
	7	4			8	8	2.00	.50	1.000		0	Wait for "ACK"
	8	6			9	13	2.00	.50	1.000		0	Wait for "COR" or "ERR"
	9	3			4	10	.70	.01	.950		0	Err change or reenter
	10				10	11	15.00	.50	.900		0	Enter change
	11		C		11	12	5.00	1.00	.900		0	Correct
	12				12	6	5.00	1.00	.990		0	Enter "CLR"
	13	3		7	14	0	0	0	.100		0	Decide if hard copy
	14	4			15	15	35.00	10.00	1.000		C	Wait for hard copy
	15			7	15	0	10.00	1.20	1.000		0	Tear off and file

Figure 2-3. Sample recording of task/analytic input data.

Generation of Message backlogs

The day starts with only the G-3/AO personnel having a potential backlog of messages to process. Based on the input BKLG (see Table A-3) which specifies the number of backlog messages, the BAKLOG subroutine generates the appropriate number of messages and data characteristics for each message:

1. cumulative message number--a sequential number assigned to a message in order starting with 1. For each new message: CMSG = CMSG + 1.

2. message priority--an integer (1 to 5) determined by generating a pseudo random number equally probable in the range 0 to 1 (RY) and comparing its value against the five values of FREP(IP, IH)--cumulative proportion of the five types of message priorities given in Table A-5. The value of priority, PRIDR (MSG, J), assigned is the smallest value of the five priorities, IP, for which RY ≤ FREP (IP, IH). Thus, in the long run, messages will be assigned priorities in accordance with input data.

3. a code indicating one of seven message types, TYPE (MSG, J), is assigned similarly to priorities. Here, TYPE (MSG, J) is assigned to be the smallest value for which a new RY ≤ FRET (IT, IH), where FRET (IT, IH), provided as input in Table A-5, indicates the cumulative proportion of messages by the seven types of messages, IT.

4. the length of the message, LENTH(MSG, J)--a function of the average number of characters in that type of message, INC(IT), and the standard deviation around that average INS(IT), both input from Table A-7. To accomplish this, a random deviate, RD (mean 0, sigma 1), is calculated by the INPOA subroutine and used in the equation:

   $$LENTH(MSG, J) = INC[TYPE(MSG, J)] + RD \cdot INS[TYPE(MSG, J)]$$

   For all backlog messages, the time of arrival, TARIV (MSG, J), is set equal to 0, the starting time for each simulation run.

The control then passes to subroutine RESHR at circle c of the flow chart. This subroutine accomplishes the required resets for the hour counter, IH = 0, and other accumulating memory registers which are utilized for hourly totals, averages, or other functions. Included here is the variable Z(M), which designates the last time during the hour (0 to 59.99) at which the individual M was simulated performing a given task element.

Hourly Message Generation

Following the reset, the simulation enters subroutine MESGEN whose function is to generate message data for all messages which will be simulated during the coming one hour period. The flow chart for this subroutine is presented in Figure B-3. It generates the cumulative message number, priority, message type, and message length in the same way as subroutine BAKLOG discussed above. In calculating message time of arrival, however, MESGEN differs from BAKLOG, and two independent cases are identified. In the case of messages which could arrive at any time during the hour, then the arrival times, TARI (MSG, J), depends on FRER(IH), and FRED(IH), the average number of times per hour which messages (either routine or other; see Appendix Table A-5) are delivered for processing. Hour numbers begin with 1 for the first hour. The arrival time is:

$$\begin{aligned} \text{TARIV(MSG, J)} &= \text{IH} - 1 + [\text{RY} \cdot \text{FRER}]/(\text{FRER} + 1), \text{ if PRIOR(MSG, J)} = 1 \\ &= \text{IH} - 1 + [\text{RY} \cdot \text{FRED}]/(\text{FRED} + 1), \text{ if PRIOR(MSG, J)} \neq 1 \end{aligned}$$

where brackets indicate counting to the nearest integer.

For example, if the desired frequency of delivery, FRER, is three times per hour, then the above equations yield a time of arrival of 0 with probability 1/6, a time of arrival 15 minutes and 30 minutes after the hour with equal probability of 1/3, and time of arrival 45 minutes after the hour with probability 1/6.

In the case of status messages (those which are assumed to arrive only at equiprobable times during the last quarter of each hour), the following equation applies:

$$\text{TARIV(MSG, J)} = \text{IH} - 1 + 0.75 + 0.25\ \text{RY}$$

These messages are superimposed on those which are generated so as to arrive over the four.

Then, messages which were generated either by BAKLOG or MESGEN are sorted in order of time of arrival, and secondarily in order by message priority within arrival time.

The message data are then optionally recorded representing the hourly work load. The A-0/G-3 queue is printed first if ORO(2) = 1. Figure 2-4 is an example of this recording. Note that this figure has columns for other information applicable to future hours, described later. The UIOD queue is then printed in a similar format if ORO(2) equals 1. This concludes the subroutine.

Man Determination

A flow chart for the man determination subroutine MANDET is given in Figure B-4 of Appendix B. This rubroutine has as its purpose the selection of a single man and a single message to simulate next. The individual selected first is the one whose current value of Z(M) is smallest. The G-3, however, is selected only to process non routine messages, and then only if the other action officers are busy. Of course, only men who are available, AVAIL(M) = 1, can be selected; in the event that a man is processing a message which will occupy him until the end of the hour, his availability indicator is set equal to 0. This selection procedure has the effect of processing all individuals as their "turn to work" arrives in the simulation, rather than to process one individual at a time for the hour. It does cause, however, the lowest numbered worker to win all ties, and therefore work more.

Having selected an individual type of operator, j is identified. Since G-3/AO personnel have man numbers 1, 2, ..., MEN(1), then J = 1 if M ≤ MEN(1). Otherwise, J = 2 since all UIOD man numbers exceed MEN(1). If, in selecting the appropriate message for the selected man to process, it is determined that no more messages are awaiting processing for the remainder of the hour, then the balance of the hour is counted as idle time: IDL(IH, M) = IH - 1 - Z(M). The selected man and all others of his type are given a value for current time equal to the start at the next hour, Z(M) = IH + 1. In this way, they will not be eligible for selection again in the current hour. In most cases, however, unprocessed messages will be awaiting assignment to men.

If there are any messages whose processing was started in the prior hour but were not completed when the model summarized the prior hours results, these are selected over those other messages which were not carried over.

DETAIL PRINTOUT FOR INSPECTION 3-19-72 APS

MESSAGES GENERATED OR CARRIED OVER FOR HOUR 1 FOR G3

ORDER	ARRIVED (SEC)	PRIORITY	TYPE	LENGTH	OUTCOME	TOTAL UNDET ERR	ERROR RETURNS	INTERUPTED MAN	INTERUPTED ELEMENT	CUMULATIV MSG NO/
1	0	1	4	181		0	0		0	7
2	580.4	3	5	42		0	0		0	2
3	900.0	1	1	331		0	0		0	6
4	900.0	1	2	295		0	0		0	4
5	1200.0	2	1	529		0	0		0	8
6	1800.0	1	4	415		0	0		0	3
7	1800.0	1	4	364		0	0		0	1
8	1800.0	1	3	77		0	0		0	5
9	3498.5	2	4	343		0	0		0	9
10	3583.8	1	5	63		0	0		0	10

Figure 2-4. Sample recording of message queue for one hour.

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A message in memory consists of a series of data in addition to the five data elements as generated by these two subroutines. The balance of the elements will be described as they are generated. However, Table 2-1 presents a composite list for reference.

In selecting the next message for the selected man to process, a G-3 or action officer is assumed to use message priority as a primary criterion and secondarily (if there are more than one message of the highest priority waiting), the oldest message, i. e., the one which has been in the "in box" longest--the one for which TARIV(MSG, J) is least.

Having paired an operator and the next message he will process, the model next asks the question: is the selected operator ready? If the arrival time of the selected message exceeds the time when the operator is available, then the subroutine scores the difference as idle time and returns to the main routine to begin message processing at the message arrival time. Otherwise, control is returned directly to the main routine to begin processing at the time when the selected man is available. In both cases, the start time, ST, is determined.

Stress Simulation

Provision is made within the model to simulate the effects of certain manifestations of anxiety and stress (circle g of Figure B-1). Specifically, differences in the stress tolerance of individuals are simulated, as are individual anxiety levels and reactions to anxiety/stress.

Stress is operationally defined as the number of nonroutine messages in the queue at a given time divided by the number of men of the current operator type. Thus, if one of three UIOD operators is being simulated and at the given time five nonroutine messages are in the UIOD queue, the stress on the operator equals 1.6. When stress value is at its minimum value of unity, it exerts no effect on performance. A stress value, STR(M), is calculated for each message during the simulated shift. Stress tolerance is simulated as a threshold, STRM(M), assigned by input to each crew member, against which the stress value is compared in order to determine program actions. Stress values which are below threshold are considered mild and to be psychologically organizing or facilitating.

Table 2-1

Message Queue Data Elements

1.	MSG		message number
2.	PRIOR	(MSG, J)	priority number of a message
3.	LENGTH	(MSG, J)	number of characters in a message to/from CCC
4.	TYPE	(MSG, J)	type of message (8 types, see parameters)
5.	TARIV	(MSG, J)	time of message arrival in queue
6.	TNUE	(MSG, J)	total number of undetected errors, i.e., errors not initially noted by man
7.	NER	(MSG, J)	number of ERR returns from ccc
8.	MAN	(MSG, J)	operator number, if msg processing overlaps an hour
9.	IFTE	(MSG, J)	first task element in next hour, if msg processing overlaps an hour
10.	OUT	(MSG, J)	outcome of message R - rejected C - completed I - incomplete
11.	CMSGNO	(MSG, J)	cumulative message number of this message, i.e., CMSG

The stress factor, SF, is a normalized stress value calculated as a function of the stress threshold STRM(M) given as input. It is arranged so that when there is no stress, SF = 0, and when stress reaches the threshold, the factor has a value of unity.

Messages of routine priority, PRIOR(MSG, J) = 1, are rejected when the stress exceeds the threshold.

Performance and Aspiration

The model defines a performance value, PERF(M), for each man to represent his changing success record (circle h of Figure B-1). Initially, PERF is set equal to his aspiration value scaled between 0 and 1. Thereafter, performance equals the ratio of number of critical task element successes to the total number of critical task elements he performs.

Provision is made to simulate the level of aspiration, or motivation, of each man. This is done by initially assigning individual aspiration values, permitting those values to affect the speed of performance, and then adjusting the aspiration values as a function of operator success records and the amount of stress being incurred.

From the input data (Table A-4), each simulated man is assigned an initial aspiration level, ASP(M). It represents the task success record that the operator would hope to attain, where success record is defined as the ratio of the number of task element successes to number of attempts. Thus, an operator with an aspiration value of 1.00 would aspire to succeed in every one of his task attempts, while an operator with an aspiration value of 0.50 would have lower motivation and would be viewed as considering a rate of one successful attempt in two as acceptable.

As simulated, level of aspiration influences working pace (via a Pace Adjustment Factor) and is in turn subject to the influence of the degree of stress the operator is incurring and his success record. The reciprocal and dynamic quality of the variable as treated in the model is quite consistent with aspiration level dynamics as described by such writers as Lewin (1942) and Kelley and Thibaut (1954). Considered are: (a) the operator's goal discrepancy--the difference between the aspired success record and the actual record, and (b) the difference between current stress on the operator and the operator's stress threshold. Comparison of the goal discrepancy with the stress differential provides the basis for the reciprocal influences involving level of aspiration. Five discrete circumstances can exist:

Case 0	Zero or near zero goal discrepancies
Case 1	Positive goal discrepancy (i.e., aspiration in excess of actual performance record) and subliminal stress
Case 2	Negative goal discrepancy and subliminal stress
Case 3	Positive goal discrepancy and stress equal to or greater than threshold
Case 4	Negative goal discrepancy and stress equal to or greater than threshold

The model logic for these cases is shown in Figure B-1, circle h.

Case 1 presents a circumstance which will be recognized as predisposing positive motivational value--the operator is not performing as well as he would like to, yet he is only mildly stressed, if at all. The psychological expectation is that he would strive to perform better, and the model effects this by generating a Pace Adjustment Factor, (PAFA), less than unity, which will later have the effect of simulating his working faster. Figure 2-5 shows this effect.

Case 2 further illustrates the dynamic aspect of level of aspiration, both as occurring in life and as simulated in the model. Presented is a negative goal discrepancy, which means that performance exceeds operator aspiration, and stress is still of only modest magnitude. Psychological theory (e.g., Deutsch, 1954) indicates that under these conditions, the operator would "raise his sights" and aspire to do more, since he demonstrated to himself that he has easily attained the initial level. In this regard, Krech and Crutchfield (1948) wrote:

> ...a successful individual typically sets his next goal somewhat, but not too much, above his last achievement. In this way he steadily raises his level of aspiration. Although in the long run he is guided by his ideal goal,..., nevertheless his real goal...is kept realistically close to his present position.

This process is simulated in the model according to a Monte Carlo procedure, in which aspiration is increased and the Pace Adjustment Factor is set equal to 1.

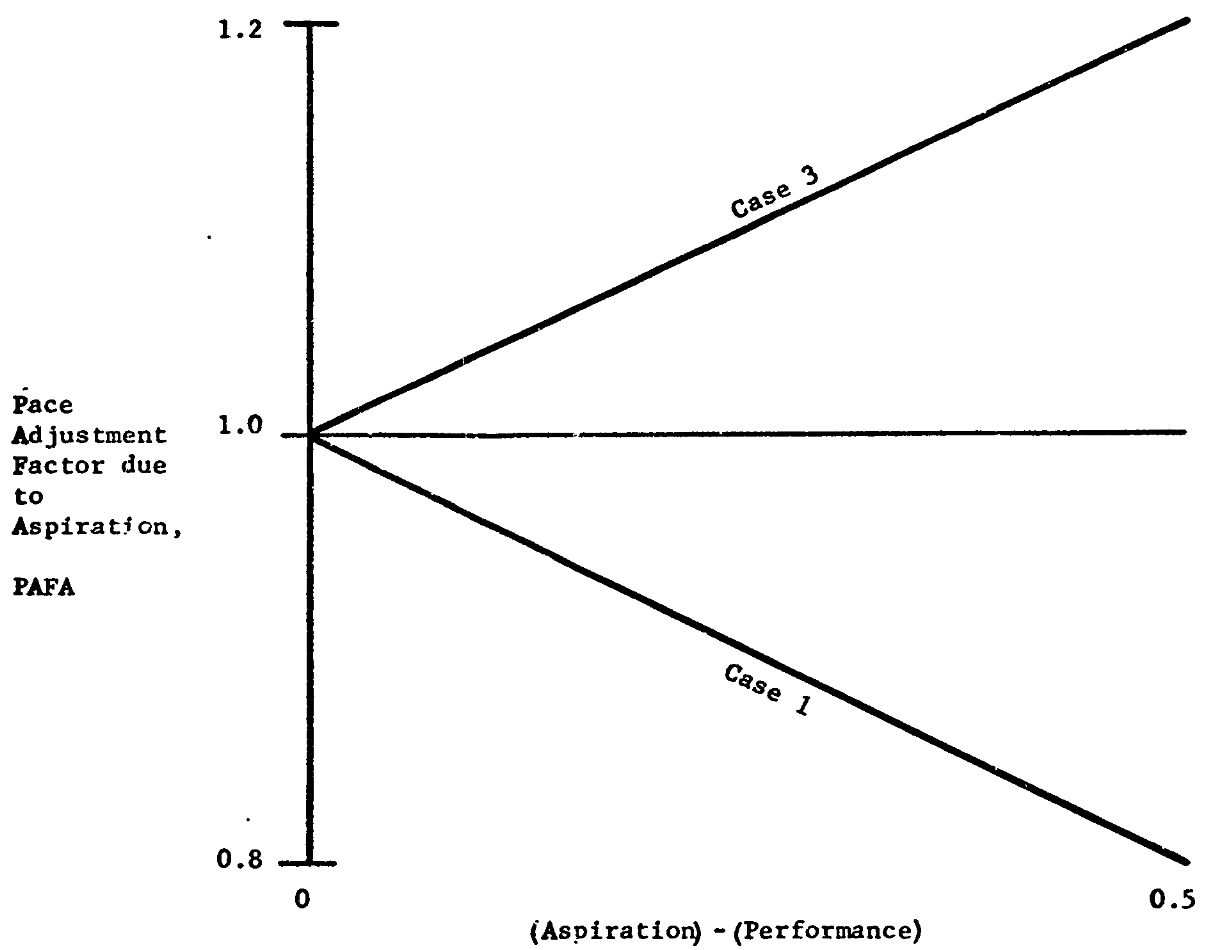

Figure 2-5. Pace adjustment factor as a function of aspiration and performance.

Case 3 presents a circumstance of resignation. The operator is not performing as well as he would like, but is incurring severe stress. Because of the severe stress, he has no choice but to accept his current performance level. The model effects this by reducing the aspiration value so that it equals the performance record. The simulated operator has ceased his upward striving and avoids the severe stress by accepting his current performance. However, associated with the cessation of upward striving, with the "edge" off the individual's motivation, one might expect to observe the beginnings of a partly voluntary and partly involuntary deterioration in performance. This effect is simulated in the model by generating PAFA > 1, which will later have the effect of slowing down the rate at which the operator performs his tasks. (See Figure 2-5.)

In Case 4, current stress is altered. Specifically, Case 4 presents the circumstances of performance exceeding operator aspiration, but stress being substantial. That is, the operator is incurring severe stress, despite the fact that he has attained the level of performance he set for himself. It seems reasonable that as he reviews his success record, he stops "sweating it" quite so desperately, for he has demonstrated that he can attain his aspiration level. In the model, this is simulated by reducing the operator's current stress to a value ten per cent below the stress threshold.

Fatigue

Provision is made in the model to simulate fatigue stress via the FATIGU subroutine. The implementation of this variable in the model is based upon a study of fatigue in air traffic controllers (Grandjean, Wotzka, Schaad, & Gilgen, 1970), in which a number of measures were taken over a 10 hour work period. In this study, 68 air traffic controllers were tested on critical fusion frequency, a tapping test, and a grid tapping test. These tests were administered nine times within 24 hours over a three week period. The results are shown in Figure 2-6. The tapping data (equally weighting the two tapping tests) were converted to a percentage of baseline plot and are shown as the heavy line in Figure 2-7. As can be seen, the trend is a very slow drop off up to six hours after starting work, following by a more abrupt drop off. Although the available data only extend through a 10 hour period, the extreme linearity of the data allow some degree of confidence in extrapolation through 12 hours.

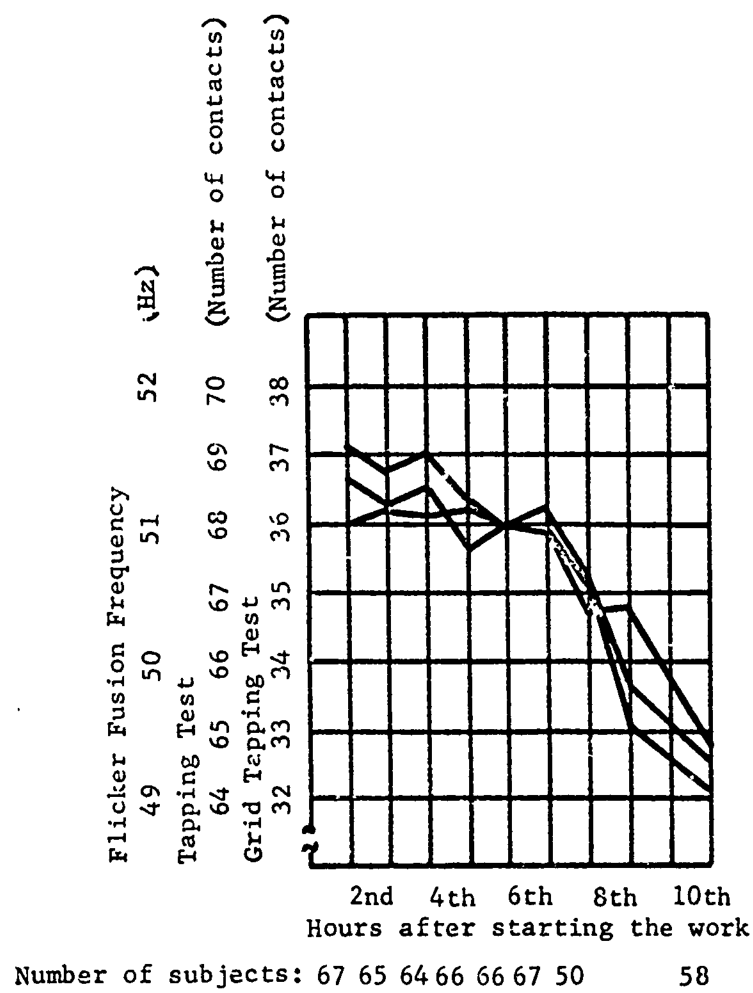

Figure 2-6. Mean values of critical fusion frequency, of a tapping and of a grid tapping test in relation to hours after starting work (from Grandjean et al., 1970).

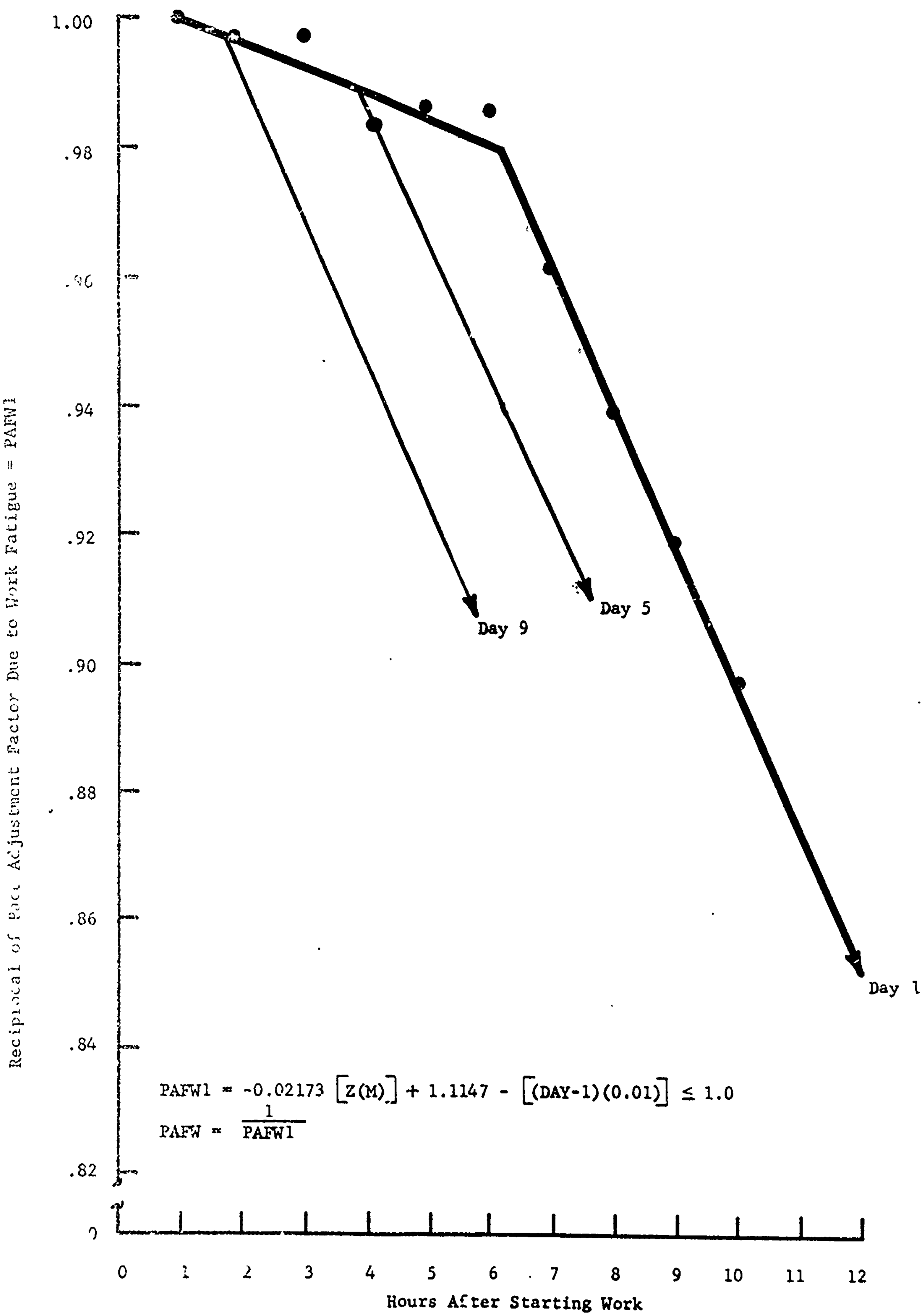

Figure 2-7. Work fatigue function.

Thus, the degrading effects of operator work fatigue are considered in the model to build as a function of the length of time elapsed since the shift began, regardless of the level of work activity. To this end, a Pace Adjustment Factor due to work fatigue, PAFW, is calculated in accordance with the data shown in Figure 2-7. Since the degradation is minimal for the first six hours, the fatigue effects for the first six hours are not considered within the model. Thus, only the fatigue effects which accrue after six hours of work are considered. Although only part of one day of a mission may be simulated in any one run, the model provides for fatigue degradation effects of the same slope but starting earlier in the shift for successive days of the mission. Two other sample day effects (days 5 and 9) are also shown in Figure 2-7.

Operator Processing Subroutine

The Operator Processing Subroutine is a miniature one-man model of the type described in Chapter I of this report. Its logic flow diagram is presented as Figure B-2 of Appendix B. This subroutine is capable of selecting the one of up to four (K) task analyses appropriate to the man being simulated and stepping him through a series of task elements to accomplish the simulation of a man processing a message.

Upon entering the subroutine, there are a series of resets in preparation for the simulated performance of the first task element, I. If: (1) the message being processed is a type 1 message (one which may be rejected during initial screening), (2) J = 1, and (3) the message is of routine priority, the message is rejected with probability AVPROB (I, K). This is accomplished by comparing AVPRB(I, K) with a rectangularly distributed random number in the range 0 to 1.

For the messages not rejected, the stress time adjustment factor, (ZIF), is calculated. A cubic equation, previously desired, to simulate the effect of stress on performance time is used. The function is presented in Figure 2-8 and reported in Siegel and Wolf (1969). The factor equals 1.0 if there is no stress (no message backlog) and decreases to a value of 0.292 when current stress equals the input parameter stress threshold for the man being simulated.

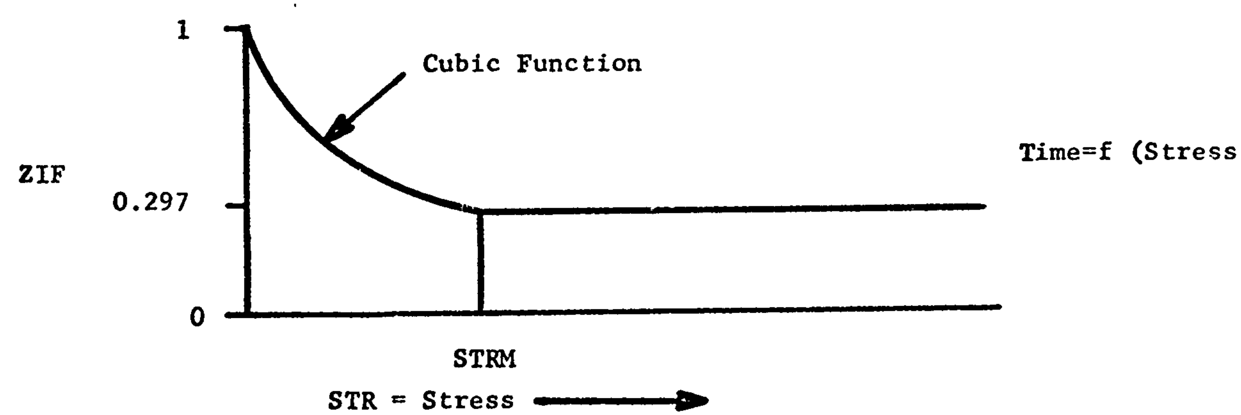

Figure 2-8. Time adjustment factor due to stress.

Thus, in the simulation, the general influence of stress is to increase the operator's working pace. (This is done by using ZIF as a multiplicative factor.) This is consistent with most views of emotional reactions as gearing the individual for overt activity; the "fight or flight" or early writers, the "stirred up state" ascribed by Garrett (1951) to Woodworth, the emphasis on activity and not passivity. Garrett speaks of "...an impulse or conscious attitude tending toward some definite activity," and further indicates "...that the term 'stirred up' means active or agitated...[1951, p. 149]." The characteristic physiological changes of increased heart rate, increased blood pressure, diversion of vascular supply from the digestive system to the exterior muscles of the trunk and limbs, adrenal secretions, "thus preparing the body for action...[Morgan, 1956, p. 90]" are all well-recognized concomitants of emotionality. The simulation reflects the activity attending emotionality by decreasing the operator's performance time as he incurs stress. So long as the stress is below the operator's stress threshold, the overall effect is facilitating, because the operator performs his tasks more quickly and with no loss in accuracy.

If the task element represents an operator decision (TYPE(I,K) = 3), the next task element I is calculated on the basis of the outcome of comparing a pseudo random number RY against AVPRB(I, K). The two-way decision has the effect of taking task element IJS(I, K) next with probability equal to AVPRB(I, K). Otherwise, task element IJF(I, K) is selected.

If the task element is an "equipment only action," then the elapsed time that the equipment takes to accomplish the task element is calculated without any effect of stress: TIME = AVGTM(I, K) + RD[SIGMA(I, K)], where RD is a random deviate and AVGTM(I, K) and SIGMA(I, K) are input data for each task element.

The following calculations for the number of unnoted errors, error returns, task element execution time, task element success determination, bookkeeping for time, and next task element determination are repeated for each task element in the selected sequence.

Errors may be made by any of the men who participate in the mission simulated. Errors are counted when an incorrect act is not noticed or corrected when it is performed. The total number of these unnoted errors, TNUE, is calculated as a Poisson distribution function with mean equal to the product of the error rate per character and the length of the message for the task element representing the TOS transform operation. All other task elements will either generate one unnoted error or no errors, depending on the undetected error probability (task analysis input Table A-8), and the operator precision (operator parameter, Table A-4). This is shown at circle B in flow chart B-2.

It is assumed that some of the errors which were made by the simulated operators will result in error responses from the CCC to the UIOD operator when he transmits the message for storage or action by the CCC. The number of such ERR responses, NER(MSG, J), is calculated as a Poisson distribution function, with mean equal to the product of the number of unnoted errors just calculated and ERPG or ERPI (from Table A-6). The value of ERPG for(J = 1)and ERPI (for J = 2) represents the best estimates of the percentage of errors for each type of mean which will later produce ERR returns.

Execution Time

Execution time is calculated basically as V = average time + (random deviate)(sigma of average time). However, to determine a specific value of the execution time, TIME, of a task element, V is multiplied by several factors. The first is the speed factor, F(M]. This speed variable is intended to summarize and represent individual differences which determine how quickly an individual performs a job. Speed of event performance is treated in the model independently from the accuracy of performance.

Each member of the simulated crew is initially assigned a value to represent his normal working speed, F(M), as input from Table A-4.

A second factor, the stress adjustment factor (ZIF) was discussed above. It provides for the influence of stress on performance time. In addition, there are two Pace Adjustment Factors which generate an influence on performance time. The effect of fatigue is accomplished using PAFW as shown in Figure 2-7. The factor for aspiration, PAFA, has no effect in aspiration cases 0, 2, and 4; its effect in cases 1 and 3 is presented in Figure 2-5. The simulated performance time for the task element is then the product of V with the other factors F(M), PAFW, and PAFA.

In cases for which the average execution time represents a per-character time (i.e., if the task element is one for which JTYPE (I, K) = 2), then the total time of the task element as determined is multiplied by the number of characters in the message, LENTH (I, K).

As each task element is completed, a determination is made as to whether one of the basic time segments of message processing has been completed. These segments are shown as T_1 through T_6 of Figure 2-9, which is adapted from Baker (1970). This enables a recording of the time of occurrence of each of the seven segment times (SEGS, see Table A-10) corresponding to these six intervals. The end of each segment is determined by the task analysis input data, END(I, K), from Table A-8 and shown in the SEGMENT column of Figure 2-3.

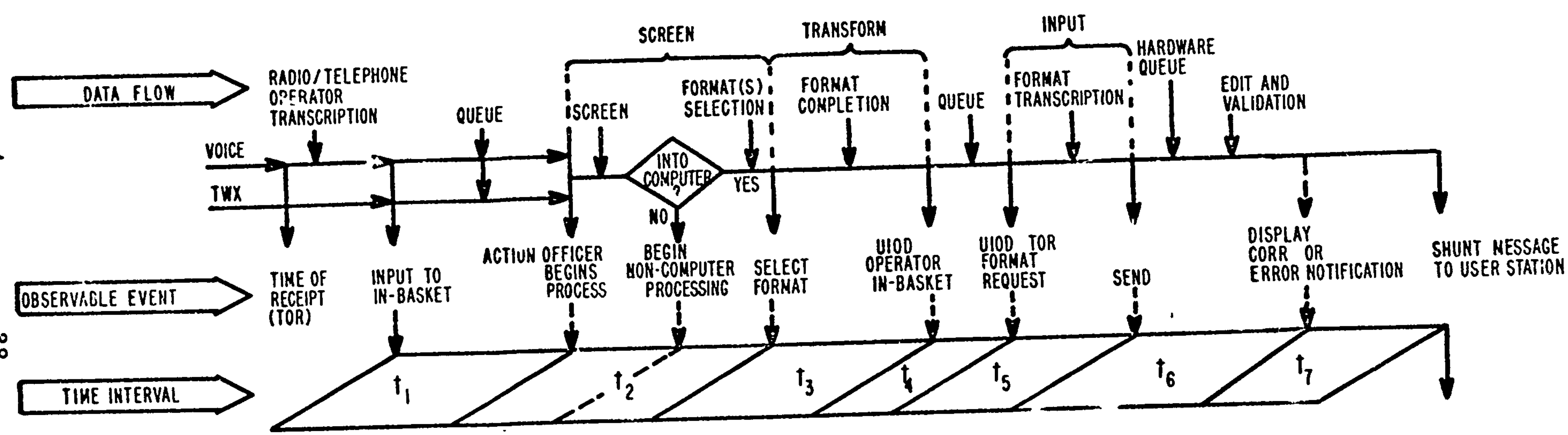

Figure 2-9. Time intervals in message processing (adapted from Baker, 1970).

Task Element Success Probability

Next, the success or failure of the task element is determined as a function of the input task element average probability of success, AVPROB(I, K) (see Table A-8), the current stress value, the stress threshold, and precision.

First, the average success probability input value is operated on by the current value of operator precision (an input parameter in Table A-4), as shown in Figure 2-10. This figure shows how the AVPROB(I, K) value is adjusted from one shown on the Y axis (as input to the model) to a new value as shown on the X axis as a function of the value of PREC(M). Sample PREC(M) values are shown. Note that no change takes place if PREC(M) equals 1. A degradation of success probability results for values of PREC(M) greater than 1.0. The opposite effect is achieved for lower PREC(M) values, and all task elements will succeed with certainty if PREC(M) equals or is less than 0.8. Note that in the model operator precision and speed are completely independent input parameters which may be adjusted individually.

The result of this adjustment is used in success determination, as shown in Figure 2-11. If stress is relatively small (i.e., less than one-quarter of the threshold value) or if the current aspiration is less than the adjusted PROB(I, K) value, then that probability value is used as the fraction against which a pseudo random number (RY) is compared to determine success or failure. Success is the result if the RY selected is the lesser. Thus, in this nominal case; success will occur with probability equal to the average input value.

If stress is higher than one-fourth of but does not exceed the threshold, and if current aspiration exceeds AVPROB(I, K), then a linearly increasing function is used to determine the function against which RY is compared. This function, given in Figure B-2 and shown in Figure 2-11, is principally dependent on stress.

If stress exceeds the threshold, then the aspiration value is used as the fraction against which RY is compared, so that the success rate in the long run will equal the aspiration in that case.

In each case, the success/failure indicator, SIF, is set to S or F as appropriate, and the processing continues at circle C of Figure B-2.

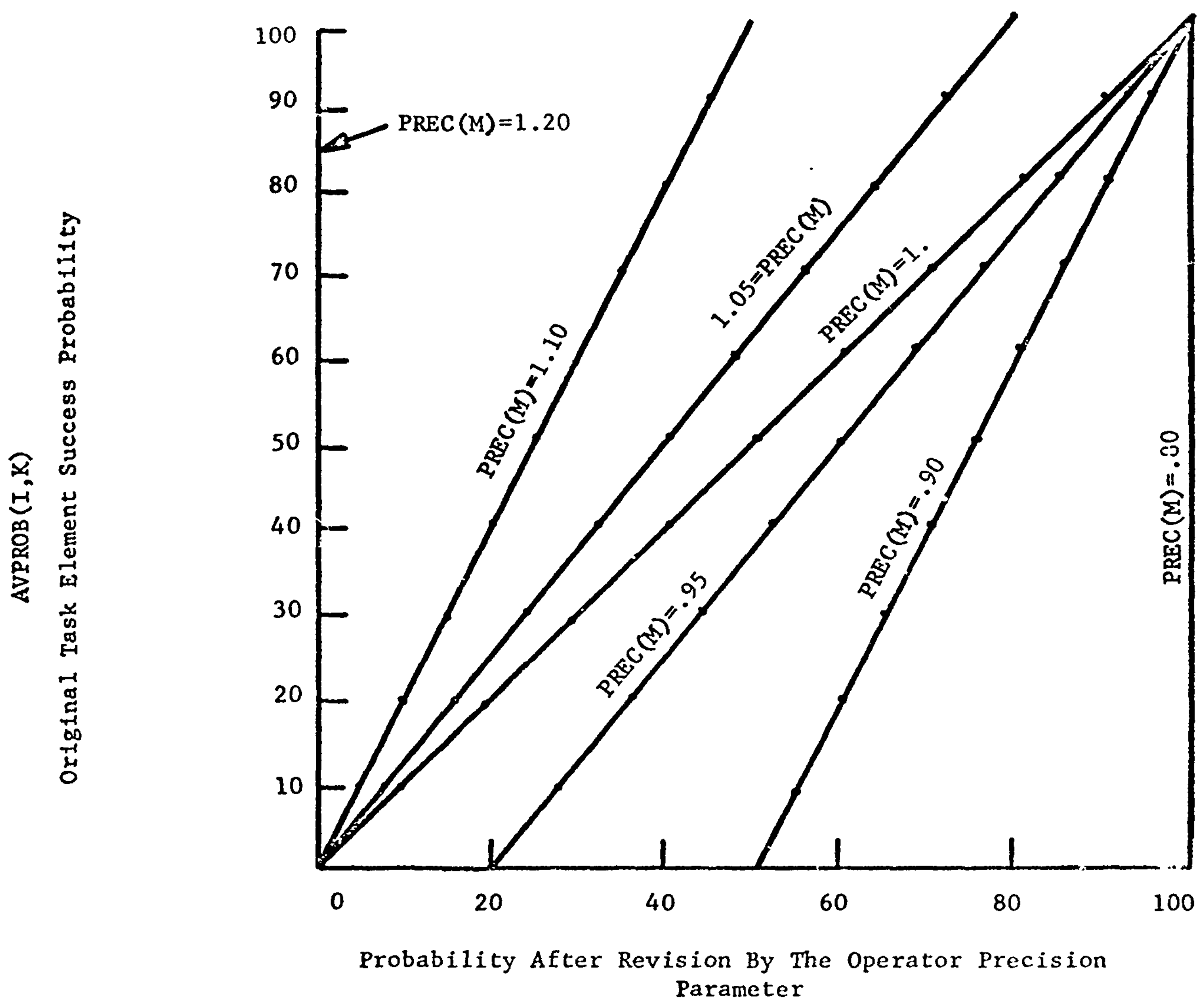

Figure 2-10. Effect of operator precision parameter on task element success probability.

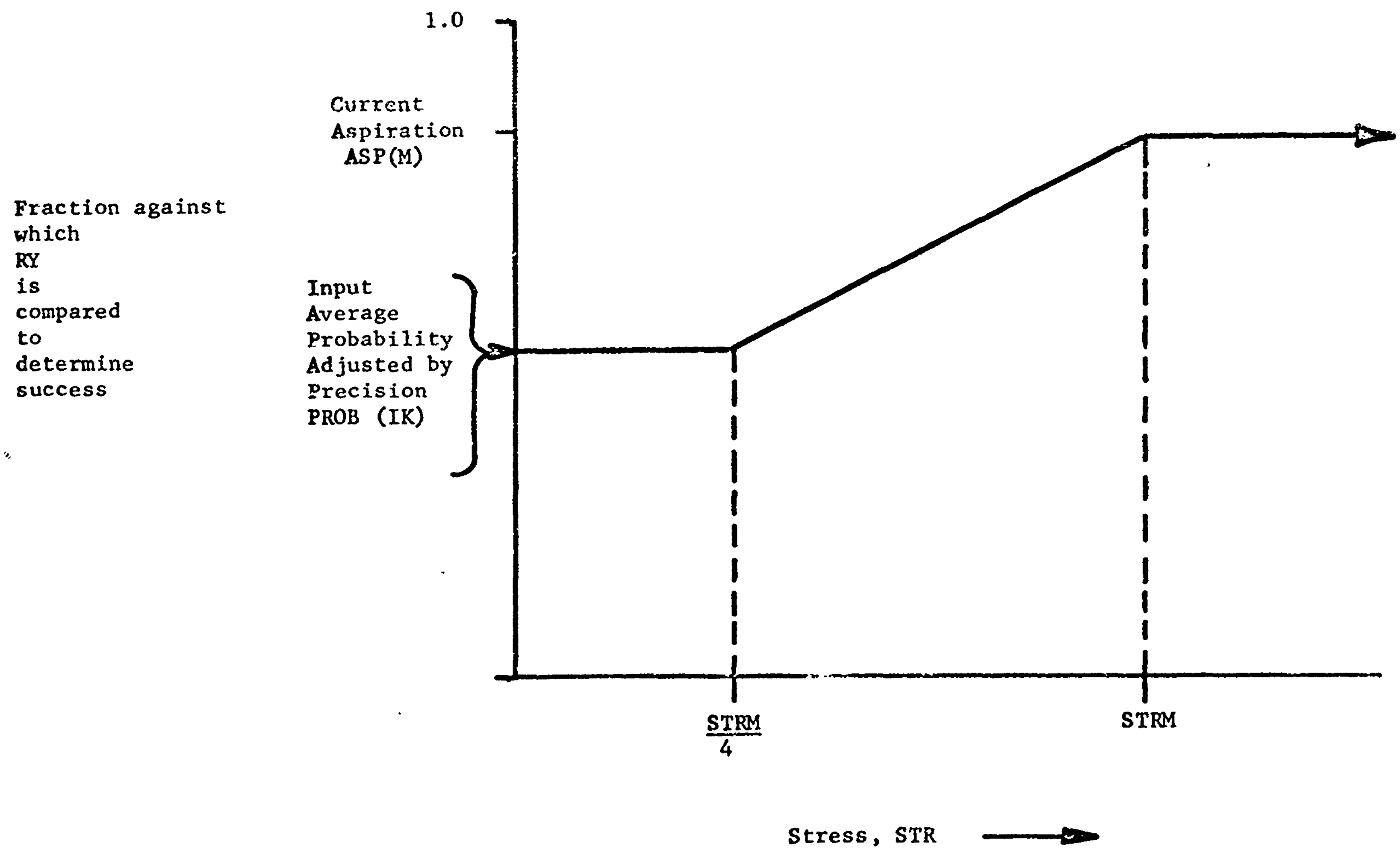

Figure 2-11. Success probability criteria as a function of stress.

The current operator time of day Z(M) and the total time worked TW(IH, M) are then adjusted as a result of the time worked on this task element.

Next, determinations are made of the next task element to be performed, and a count is kept of the number of successful and unsuccessful task elements for use in calculating performance. If the completion of this task element ran over into the next hour, the message processing results for the current hour are separated, message and task data are retained for the next hour's queue, and an indicator for nonavailability of the current man for the balance of the hour is set.

Task element results are then recorded if ORO(4) has a value of 1.

This entire procedure, controlled by the PROC subroutine, is repeated for all task elements in the task analyses list selected. In accordance with IJS(I, K) and IJF(I, K) values and success or failure outcomes of task elements, this sequence can be linear (i. e., straight sequential) or can include skips and loops. In any case, at the completion of the last task element, the results of the processing of the selected message by the selected man are printed if ORO(5) equals 1. Two samples of this tabulated output are shown for illustrative purposes. In Figure 2-12, a sample message (CMSG = 7) results by the AO-1 are shown. Outcomes from this same message as processed by UIOD-1 are shown in Figure 2-13.

Information Loss

Following completion of operator task element processing, control returns to the main routine where a variable called the information loss (INFOLS) is calculated. Information loss is directly proportional to the total number of undetected errors and proportional to the number of characters in the message. Information loss is also a function of the probabilities of errors going unnoticed in the CCC data base. Such errors of significant importance (probability = PUS) are weighted ten times more heavily than those of little importance (probability = PUL). When the INFOLS is less than one, it is set at zero and reported accordingly.

This completes all processing required for a given hour. The hour is determined to be over when all men have reached the end of their allotted time or when they have completed all messages which arrive during the hour (whichever occurs first). When this occurs, the program continues (at circle f of Figure B-1) with the calculation of efficiency.

DETAIL PRINTOUT FOR INSPECTION 3-19-72 APS

MESSAGE NUMBER	7	MAN	AO-1	DAY	1
MESSAGE TYPE	REL	STRESS FACTOR	1.00	HOUR	1
MESSAGE ORDER	1	FATIGUE	1.00	ITERATION	1
		ASPIRATION	1.00		
		CUM. IDLE	0		

MESSAGE ARRIVAL 0
MESSAGE START 0

ELEMENT NO.	EXECUTION TIME	CUMULATIVE TIME	OUTCOME (SFR)	TYPE OF ELEMENT	CRITIC -ALITY	SEGMENT ENDED	ERROR TYPE	ERROR RETURNS
1	9.80	9.80	S	1				0
2	4.88	14.68	F					0
2	3.34	18.02	S					0
3	18.38	36.40	S					0
4	18.50	54.90	S		C	3		0
5	14.05	68.96	F					0
5	14.83	83.79	S					0
6	11.75	95.54	S					0
7	87.02	182.56	S	2			T	2
8	7.99	190.55	F		C			2
9	12.88	203.43	S					2
10	14.72	218.15	S		C	4		2

MESSAGE 7
PROCESSED BY AO-1

TRANSFORM ERRORS	
COMMISSION	3
ABREV/TYPO/SPAC	8
OMISSION	4
OTHER ERRORS	0

TOT. UNDET. ERRORS	15
NO. ERROR RETURNS	2
INFORMATION LOSS	0

Figure 2-12. Sample detailed message processing output.

Efficiency

Baker (1970) defined four systems performance measures for the TOS system--thoroughness, completeness, responsiveness, and accuracy. For the model, each of these was framed in terms of model variables calculated. They were combined into a single efficiency function calculated at the completion of each hour's processing and averaged over the shift as a summary of iteration performance.

Each component as well as the total efficiency is scaled in the range from zero (complete inefficiency) to one (perfect efficiency).

The first efficiency component, EC(1), representing thoroughness, is the ratio of the number of message blocks completed during the hour to the total number of message blocks which could potentially have been completed during the hour. Here, message block is the completion of one message by one man. Completeness, EC(2), is defined as the sum of performance, PERF(M), values summarized over all men (performance represents the percentage of successful task elements).

The third component, responsiveness, is determined by a linear function such that EC(3) will have a value of 1.0 only in the impossible case in which the average message processing time is zero. From this, responsiveness decreases linearly to zero when the average message processing time equals or exceeds 600 seconds:

$$EC(3) = 1 - \left[\frac{\text{Average message processing time}}{600}\right]$$

Accuracy is determined from the relationship:

$$EC(4) = 1 - \left[\frac{\text{Total information loss}}{\text{Number of messages completed}}\right]$$

where total information loss is the sum of INFOLS values overall messages for the hour. Responsiveness will then approach perfection as information loss approaches zero.

In evaluating systems like TOS where these four different measures of effectiveness are involved, a problem exists concerning their combination in order to form a simple numerical index which describes "overall effectiveness."

Appendix C contains a set of 6 criteria for such a combinatorial process. It then describes the function derived for the TOS model which satisfies these criteria, and discusses output reasonableness for the function:

From Appendix C, the efficiency function in FORTRAN notation for four components is:

$$\mathrm{EFF} = \left[\frac{CC12 + CC13 + CC14 + CC23 + CC24 + CC34}{6}\right] \cdot$$

$$[W(1)(EC(1) + W(2)(EC(2) + W(3)(EC(3) + W(4)(EC(4)]$$

$$+ \left[\frac{6 - |CC12| - |CC13| - |CC14| - |CC23| - |CC24| - |CC34|}{6}\right] \cdot$$

$$[EC(1)^{\frac{1}{W(1)}}][EC(2)^{\frac{1}{W(2)}}][EC(3)^{\frac{1}{W(3)}}][EC(4)^{\frac{1}{W(4)}}]$$

Sample output is presented, in context, in Figure 3-3.

Result Recording

Following this calculation, the summarized results of the entire hour's message processing load are recorded for printing (if the printing system, ORO(6), was input equal to 1). A sample of this output showing the format and content of hourly results is in Figure 2-14.

This process is repeated for each hour from circle c through circle f. When the program has completed all of the required (IHMAX) hours in a shift, subroutine ITSUM is entered to summarize all hourly results for that single shift iteration.

After completing a series of NSHF iterations of such IHMAX hour shifts, subroutine RUNSUM summarizes all results for the run. Outputs are printed which encompass manpower utilization, time segment data by hour, message type, and message priority, a workload summary and error summary. Figures 2-15 through 2-18 are samples of these outputs.

This completes the processing for a run, but the entire process can be repeated by readin of additional input data for one or more subsequent runs.

DETAIL PRINTOUT FOR INSPECTION 3-19-72 APS

END OF HOUR RESULTS HOUR 1
DAY 1
ITERATION 1

OPERATOR PERFORMANCE DATA

	--MESSAGES--			--TIME--		--------FINAL------		
MAN	COMPLETED	REJECTED	INTERRUPTED	WORKED	OTHER	STRESS	ASPIRATION	PERFORM
1	4	1	1	1295.0	2305.0	0	.90	.64
2	3	0	1	586.6	3013.4	0	.90	.50
3	0	0	0	0	3600.0	0	.90	.90
4	2	0	0	2029.2	1570.8	0	.90	.40
5	3	0	0	486.9	3113.1	0	.90	.38
6	2	0	0	1004.9	2595.1	0	.90	.34

MESSAGE PERFORMANCE DATA
AVERAGE TIME PER MESSAGE 759.3
MESSAGES IN AO-63 QUEUE AT HOUR START 10
TOTAL INFORMATION LOSS 1
EFFECTIVENESS COMPONENTS
THOROUGHNESS .82
COMPLETENESS .53
RESPONSIVENESS 0
ACCURACY .86

EFFECTIVENESS= .28

DETAILED MESSAGE TIMING

CUMULATIVE MESSAGE NUMBER	TYPE	T1	T2	T3	T4	T5
1	4	0	55.1	273.7	10.8	230.6
2	5	0	19.2	120.8	23.6	70.8
3	4	0	40.3	252.1	17.4	173.9
5	3	292.4	38.6	99.5	102.5	40.4
6	1	0	42.6	216.3	16.3	652.7
7	4	0	54.9	163.2	12.0	328.9
8	1	0	61.6	326.1	9.8	1569.4

MESSAGE TYPE	NUMBER COMPLETED	T1	T2	T3	T4	T5
1	2	0	52.1	271.2	13.1	1111.0
2	0	0	0	0	0	0
3	1	292.4	38.6	99.5	102.5	40.4
4	3	0	50.1	229.7	13.4	244.5
5	1	0	19.2	120.8	23.6	70.8
6	0	0	0	0	0	0
7	0	0	0	0	0	0

Figure 2-14. Sample end of hour results.

DETAIL PRINTOUT FOR INSPECTION 3-19-72 APS

RUN SUMMARY

MANPOWER UTILIZATION

HOUR	MAN	TIME WORKED	PROP	TIME OTHER	MESSAGES PROCESSED	MEAN TIME PER MESSAGE	FINAL STRESS	FINAL ASPIRATION
1								
	1	1295	.36	2305	4	298	0	.900
	2	587	.16	3013	3	190	0	.900
	3	0	0	3600	0	0	0	.900
	4	2029	.56	1571	2	1015	0	.900
	5	487	.14	3113	3	162	0	.900
	6	1005	.28	2595	2	502	0	.900
2								
	1	1598	.44	2002	6	293	0	.900
	2	1391	.39	2209	7	201	0	.900
	3	0	0	3600	0	0	0	.900
	4	1625	.45	1975	6	265	0	.900
	5	2138	.59	1462	2	1069	0	.900
	6	870	.24	2730	3	274	0	.900
3								
	1	1896	.53	1704	7	271	0	.900
	2	1749	.49	1851	8	219	0	.900
	3	0	0	3600	0	0	0	.900
	4	1811	.50	1789	4	401	0	.900
	5	1056	.29	2544	5	202	0	.900
	6	1722	.48	1878	5	351	0	.900
4								
	[illegible]	780	.22	2820	3	266	0	.900
	2	524	.15	3076	2	262	0	.900
	3	0	0	3600	0	0	0	.900
	4	695	.19	2905	2	301	0	.900
	5	883	.25	2717	2	464	0	.900
	6	579	.16	3021	2	297	0	.900
MEANS FOR EACH MAN PER MESSAGE UNIT								
	1	1392	.39	2208	20	279	0	.900
	2	1063	.30	2537	20	213	0	.900
	3	0	0	3600	0	0	0	[illegible]
	4	1540	.43	2060	14	429	0	.900
	5	1141	.32	2459	12	380	0	.900
	6	1044	.29	2556	12	348	0	.900
GRAND MEANS								
		1030	.29	2570	13	275	0	.900

Figure 2-15. Sample run summary (1).

DETAIL PRINTOUT FOR INSPECTION 3-19-72 APS

TIME SEGMENTS

	----T1----		----T2----		----T3----		----T4----		----T5----		TOTAL	N
HOUR	TIME	PROP	TIME	PROP	TIME	PROP	TIME	PROP	TIME	PROP	(SUM)	CPL
1	42	.06	45	.06	207	.27	27	.04	438	.58	759	7
2	349	.36	61	.06	193	.20	19	.02	354	.36	976	11
3	26	.05	52	.10	171	.34	12	.02	249	.49	510	14
4	73	.11	74	.11	198	.29	17	.02	327	.47	688	6
CAN	130	.18	57	.08	188	.26	18	.02	326	.45	719	38

[illegible]	----T1----		----T2----		----T3----		----T4----		----T5----		TOTAL	N
[illegible]	[illegible]	PROP	TIME	PROP	TIME	PROP	TIME	PROP	TIME	PROP	(SUM)	CPL
1	0	0	50	.04	255	.22	16	.01	867	.73	1188	5
2	523	.42	74	.06	199	.16	14	.01	435	.35	1246	7
3	97	.23	57	.14	150	.36	43	.10	70	.17	417	3
4	57	.10	65	.11	197	.33	16	.03	261	.44	597	17
5	0	0	18	.09	115	.55	14	.07	63	.30	211	6

IOR	----T1----		----T2----		----T3----		----T4----		----T5----		TOTAL	N
MSG	TIME	PROP	TIME	PROP	TIME	PROP	TIME	PROP	TIME	PROP	(SUM)	CPL
1	171	.24	58	.08	185	.26	19	.03	275	.39	707	28
2	30	.03	72	.07	250	.23	14	.01	717	.66	1083	5
3	0	0	34	.08	146	.35	15	.04	225	.53	420	5

Figure 2-16. Sample run summary (2).

DETAIL PRINTOUT FOP INSPECTION 3-19-72 APS

WORKLOAD SUMMARY

HOUR	BACKLOG AO/G3	BACKLOG IOD	MESSAGES DELIVERED LAST 1/4 HR	MESSAGES DELIVERED ANYTIME	MESSAGE UNITS COMPLETED AO/G3	MESSAGE UNITS COMPLETED IOD	MESSAGE UNITS REJECTED AO/G3	MESSAGE UNITS REJECTED IOD	MESSAGE UNITS INTERUPTED AO/G3	MESSAGE UNITS INTERUPTED IOD
1	0	0	2	8	7.0	7.0	1.0	0	2.0	0
2	3.0	0	2	8	13.0	11.0	0	0	0	2.0
3	0	2.0	3	12	15.0	14.0	0	0	0	3.0
4	0	3.0	2	3	5.0	6.0	0	0	0	1.0

Figure 2-17. Sample run summary (3).

DETAIL PRINTOUT FOR INSPECTION 3-19-72 APS

ERROR SUMMARY - BY HOUR

HOUR	ERROR TYPE 1	ERROR TYPE 2	ERROR TYPE 3	ERROR RETURNS	INFORMATION LOSS	NUMBER OF MESSAGES UNITS
1	4.93	8.00	13.67	3.87	.13	15
2	9.13	5.74	11.57	3.39	.09	23
3	9.45	5.31	9.79	2.62	0	29
4	5.64	3.82	8.36	4.73	0	11

ERROR SUMMARY - BY MESSAGE TYPE

MESSAGE TYPE	ERROR TYPE 1	ERROR TYPE 2	ERROR TYPE 3	ERROR RETURNS	INFORMATION LOSS	NUMBER OF MESSAGES UNITS
1	33.80	17.80	35.40	9.40	.40	10
2	14.57	8.29	16.00	6.00	0	14
3	1.33	1.67	2.67	.67	0	6
4	5.00	3.61	5.94	2.00	0	36
5	3.33	1.17	2.50	.83	0	12

Figure 2-18. Sample run summary (4).

CHAPTER III

SENSITIVITY TESTS

In order to examine the model's output for consistency, realism, and reasonableness of relationships over a selected range of input parameters, a series of tests was performed. The methods and results of these tests are described in Chapter III of this report.

Test Methods

Independent Variables

Three major variables were selected for a systematic manipulation during the model tests. These variables were operator skill level, operator mix (i.e., number of action officers and UIOD operators), and message workload.

Operator skill level is described within the model by four different variables: SPEED, PREC, STRM, and ASP, described in detail in the previous chapter. The stress threshold value was held constant at 10 messages, while the other three variables were systematically varied, as shown in Table 3-1. The three levels of operator level selected will be referred to as levels I, II, and III, which indicate above average, average, and below average respectively.

Table 3-1

Operator Skill Level Variable Assignments

		SPEED	PREC	ASP
I.	Above average	.8	.9	.98
II.	Average	1.0	1.0	.90
III.	Below average	1.2	1.05	.75

The total number of operators was held constant at six, and the two operator mixes used were 2/4 and 3/3, where the first number of each pair refers to the number of action officers, including the G-3, and the second number refers to the number of UIOD operators. This operator mix variable was combined factorially with operator skill level in the first six runs of the sensitivity tests.

Message workload was varied in two ways. Workloads of 5, 10, and 15 messages per hour were used. Whichever workload was selected for a particular run remained constant for an eight hour workday.

Within workloads, the percentage of messages arriving randomly throughout the last 15 minutes of the hour was varied. The two percentages used were 80/20 and 60/40, where the first number of each pair refers to the percentage of messages arriving this hour and which arrived randomly throughout the hour, and the second number refers to the percentage of messages arriving this hour which came in randomly throughout the last 15 minutes of the hour.

Table 3-2 shows the independent variables for each of the 11 sensitivity test runs. For the first six runs, message workload per hour was held constant at 10, with 80 per cent of the messages arriving randomly throughout the hour while operator factors were varied. For the last five runs, operator skill was held constant at level II (average) and operator mix was held constant at 3/3 while message workload was varied.

Table 3-2

Parameters Varied in Sensitivity Tests

Run	Operator Skill Level	Operator Mix AO/UIOD	Messages Arriving Randomly/Last 1/4 Hour
1	II	3/3	8/2
2	III	3/3	8/2
3	I	3/3	8/2
4	II	2/4	8/2
5	III	2/4	8/2
6	I	2/4	8/2
7	II	3/3	4/1
8	II	3/3	12/3
9	II	3/3	3/2
10	II	3/3	6/4
11	II	3/3	9/6

All of the input data for the TOS model may be manipulated either singly or in combination. The following sections describe the input values which were not varied during the tests. Few of these data may be regarded as immune from later manipulation. However, the difficulty in interpreting the results where too many factors are varied at one time must always be taken into consideration in testing of this kind.

Simulation Parameters

The variable NSHIFT which controls the number of repetitions of each run was set to 20. This means that the output values described later will represent the means over all 20 iterations of the run. This value for NSHIFT was selected as a result of several test cases which indicated that little difference was shown if the run was repeated 20, 40, or 60 times, whereas an NSHIFT of 10 was found to yield insufficient stability.

The runs were all set for an eight hour (IHMAX) run on day (IDAY) number one. The number of messages in the action officer's inbox at the beginning of a shift (BKLG) was set to zero.

The probability that an undetected error which is in the CCC computer data bank is of low importance (PUL) was selected to be 0.05, while the probability of such an error being significant (PUS) was selected to be 0.13.

The task analysis selector key (IATA) was set so that for operator type 1 (i.e., action officer or G-3) task analysis, number 1 was used for all message types except "Query." For the "Query" message type, task analysis 2 was used. For operator type 2 (i.e., UIOD operator), task analysis 3 was used for all message types.

Hour Parameters

The cumulative proportional message frequency employed for message types (FREO) through 7 was: .17, .42, .50, .84, .98, .99, and 1.00. This means that the probability that any given message was type Add was 0.17, the probability of a Change was 0.25 (i.e., .42 minus .17), the probability of a De te was 0.08, etc.

The cumulative proportional frequencies employed for each message priority (FREP) from 1 to 3 was :0.7, 0.9, 1.0. Therefore, the probability that any given message was "Routine" was 0.7, the probability of a "Priority" message was 0.2, and the probability of an "Operative Immediate" message was 0.1.

The frequency per hour with which routine messages were received from the communications van (FRER) was set at 3, while the frequency with which nonroutine messages were received from the communications van (FREO) was set at 11.

Error Frequency

Figure 2-2 contains the input error rates (ER) by type of error for each message type. These represent error rates per 100 characters of formatted copy. These errors represent total errors produced by both the action officer and the UIOD operator on the final copy.

Only some of the errors will produce computer error returns. The proportion of these errors which have been caused by the action officer or the G-3 and will cause an error return (ERPC) was set at .12, while the proportion due to the UIOD operator was set at .013.

Message Length

Figure 2-2 also includes the mean number of characters and the standard deviation for each message type. These cell entries represent characters in the transformed message.

Task Analyses

Figure 2-3 presents the task analyses used in the sensitivity tests. Task analysis I shows the procedure used by the action officer or the G-3 in the preparation of all message types, except for the "Query" type. Task analysis II represents the activities of the action officer in the preparation of "Query" messages. Task analysis III identifies the procedure and appropriate computer input data for all UIOD processing of messages.

Effectiveness Components

The correlation among the components of overall effectiveness is required in the computation of overall effectiveness. A correlation of .50 was assumed between each pair of components.

Each of the four components of effectiveness--thoroughness, completeness, responsiveness, and accuracy--were weighted equally (i.e., 0.25) in the computation of overall effectiveness.

Effects of Operator Skill Level

Figure 3-1 shows the mean percentage of time indicated by the simulation to be worked by the AO's, the G-3, and the UIOD operators as a function of operator skill level. The above average (level I) AO's were indicated to be occupied only 26 per cent of the time, while the average (level II) skill level AO's were indicated to work 34 per cent of the time. The below average (level III) AO's were indicated to work 48 per-cent of the time to keep up with this message workload. The G-3, who works only on high priority messages and then only if the AO's are busy when the message comes in, was indicated to work (i. e., process messages) zero time when the other crew members were at level I, one per cent of the time when the other crew members were at level II, and five per cent of the time with a below average crew. In these runs, the operator mix was held constant at two AO's, one G-3, and 3 IOD's, and the message workload was held constant at 10 messages per hour for an 8 hour shift.

These simulation results, which indicate that less skilled crews will work more slowly and, accordingly, work for a greater proportion of the time, seem entirely reasonable and in accord with expectation. Moreover, they support a contention favoring the sensitivity of the TOS model's output to skill level variation.

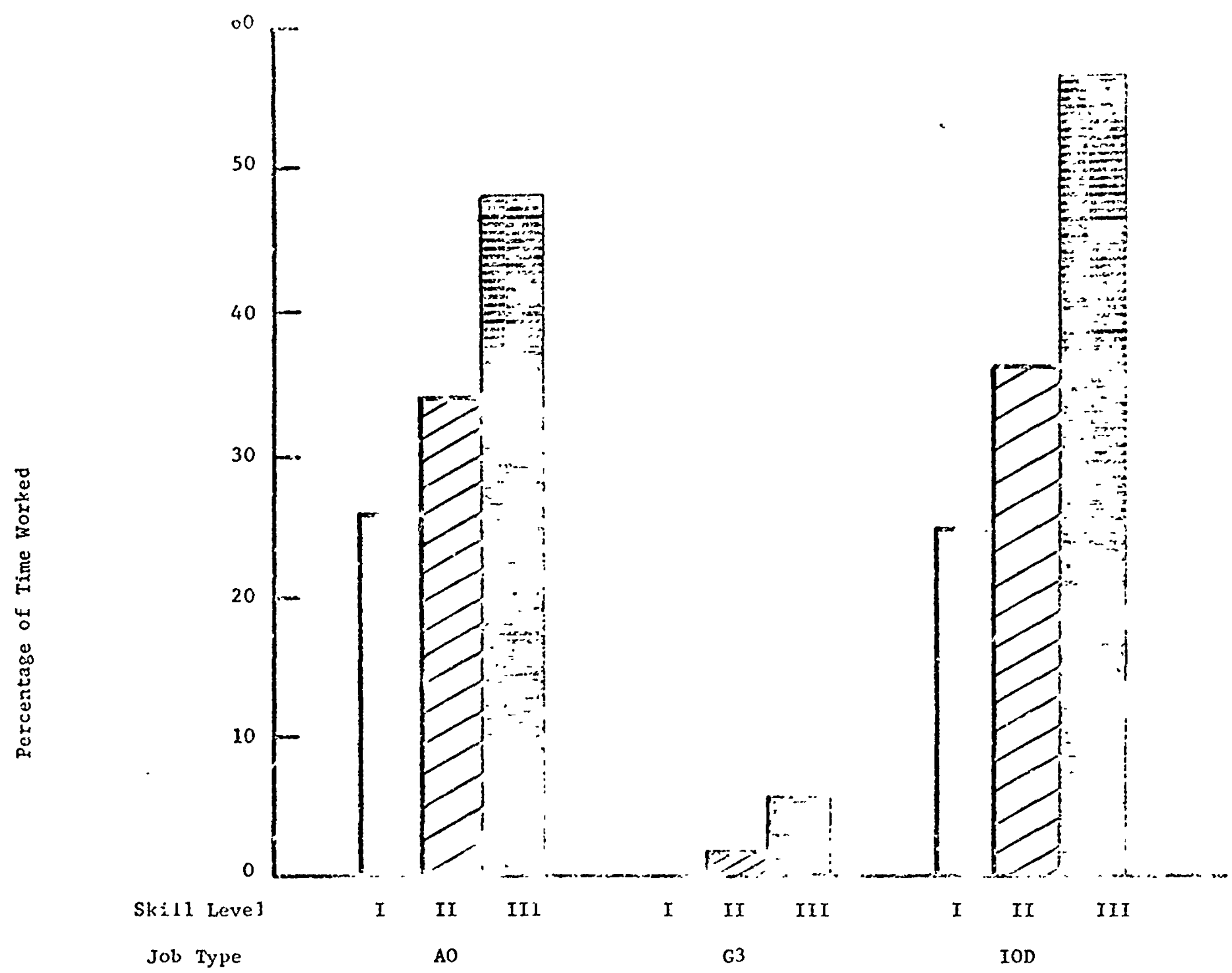

Figure 3-1. Effect of operator skill level on percentage of time worked with message workload held constant.

As would be anticipated from the prior results, operator skill level also exerted a very strong and consistent effect on time required per message. Figure 3-2 presents the mean time required for each of the five time segments of message processing for each skill level. (Note that the scaling of the ordinate of Figure 3-2 changes at 100 seconds.) In every time segment, the average skill level operator team required less time per message than the below average skill level operator team, and the above average operator team required less time than the average operator team. These differences are cumulative and are reflective maximally if one considers the total message times. The above average team required only 485 seconds on the average to complete a message, while the simulated average skill team required 658 seconds, and the below average team required 1089 seconds. Thus, the simulated average skill team processed a message in 60 per cent of the time required by the below average team, and the above average team processed a message in only 45 per cent of the time required by the below average team.

These results are also in the anticipated direction, and they suggest that this message processing time output is sensitive to skill level variation.

System Efficiency

Other model output data include the overall system efficiency index and indices of the four efficiency components of the overall index. These are shown as a function of operator skill level in Figure 3-3. For all the components of efficiency (except for the accuracy component whose score was about equal for all three skill levels), the below average operator team was exceeded by the average operator team, and the simulated above average skill team was indicated to perform more efficiently than the average skill level team.

However, we note that the responsiveness component was depressed to almost zero in one case, and that it seems unrealistically low for the other two skill level cases. Additionally, the accuracy component was indicated to be insensitive to simulated variations in operator skill level. Accordingly, it seems that reexamination and calibration of the accuracy and the responsiveness components are indicated.

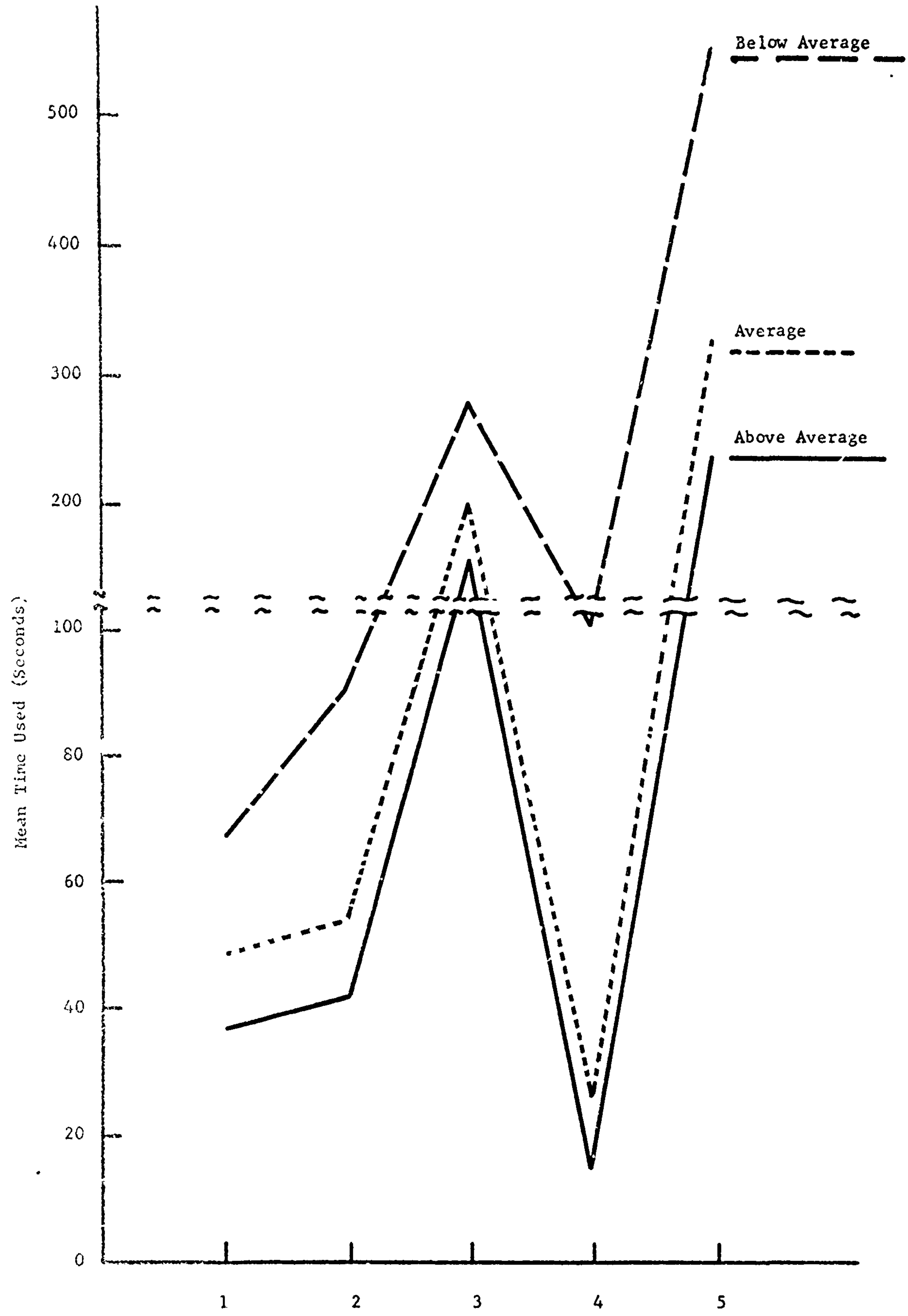

Figure 3-2. Mean time used per time segment by different operator skill levels.

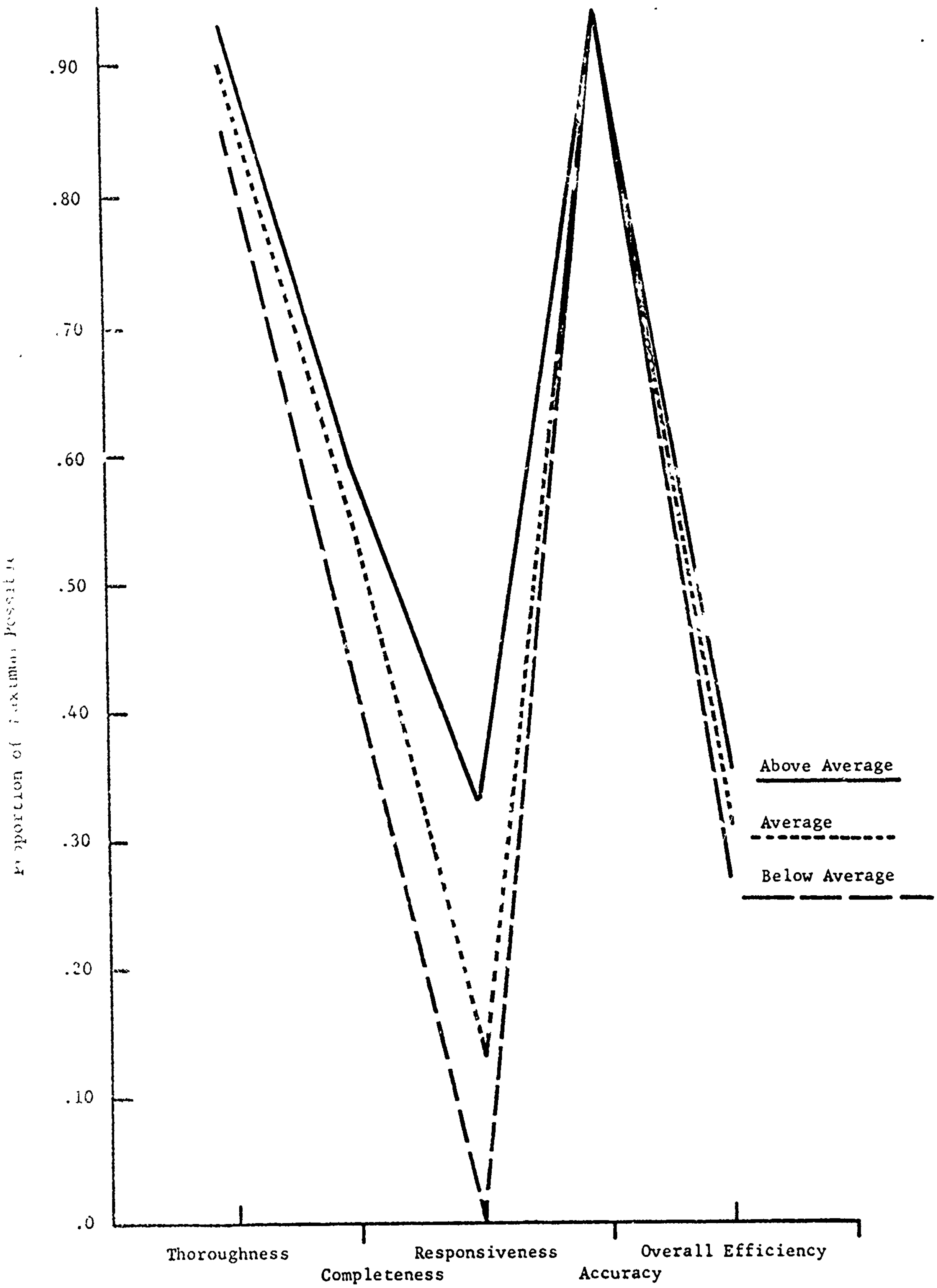

Figure 3-3. Effectiveness as a function of operator skill level.

Carried Over and Completed Messages

Operator skill level would also be anticipated to affect the number of messages carried over (and completed) each hour. Figure 3-4 shows the mean number of messages in the backlog (i. e., waiting or partially completed from the previous hour) in the action officer and in the UIOD operator queues for each skill level (and the mean number of messages completed). The simulated below average action officers carried over an average of 1.1 messages each hour, while the average action officers carried over 0.7 message and the above average action officers carried over 0.6 message. Due to the late arrival possibility, even under the best of conditions and with the best of personnel, some messages may always be carried over to the next hour.

Message backing in the UIOD's queue also reflected the effects of operator skill level. The below average UIOD's carried over 2.3 messages; the average UIOD's carried over 1.4 messages, and the simulated above average operators carried over 0.8 message per hour.

Figure 3-4 also presents the mean number of messages completed as a function of skill level. The sum of the number of messages carried over and completed per hour is greater than 10 in some cases, even though only 10 messages come in each hour. The reason for this is that, after the first hour, messages which have been started the previous hour are completed in the current hour. Accordingly, the carry over plus the arriving messages is greater than 10. The messages completed aspect of Figure 3-4 shows only slight differences between the three skill levels, although all of the differences are in the expected direction (i. e., more skilled operators complete more messages per hour). These data, taken together with the data presented in Figure 3-1, suggest the message workload involved to be manageable by any of the team skill levels involved. However, the less skilled simulated teams worked much longer in order to keep up with the workload. Finally, both the carry over and the completed messages results seem to indicate a reasonable output trend for these TOS model output data and a sensitivity of these outputs to simulated team skill level variation.

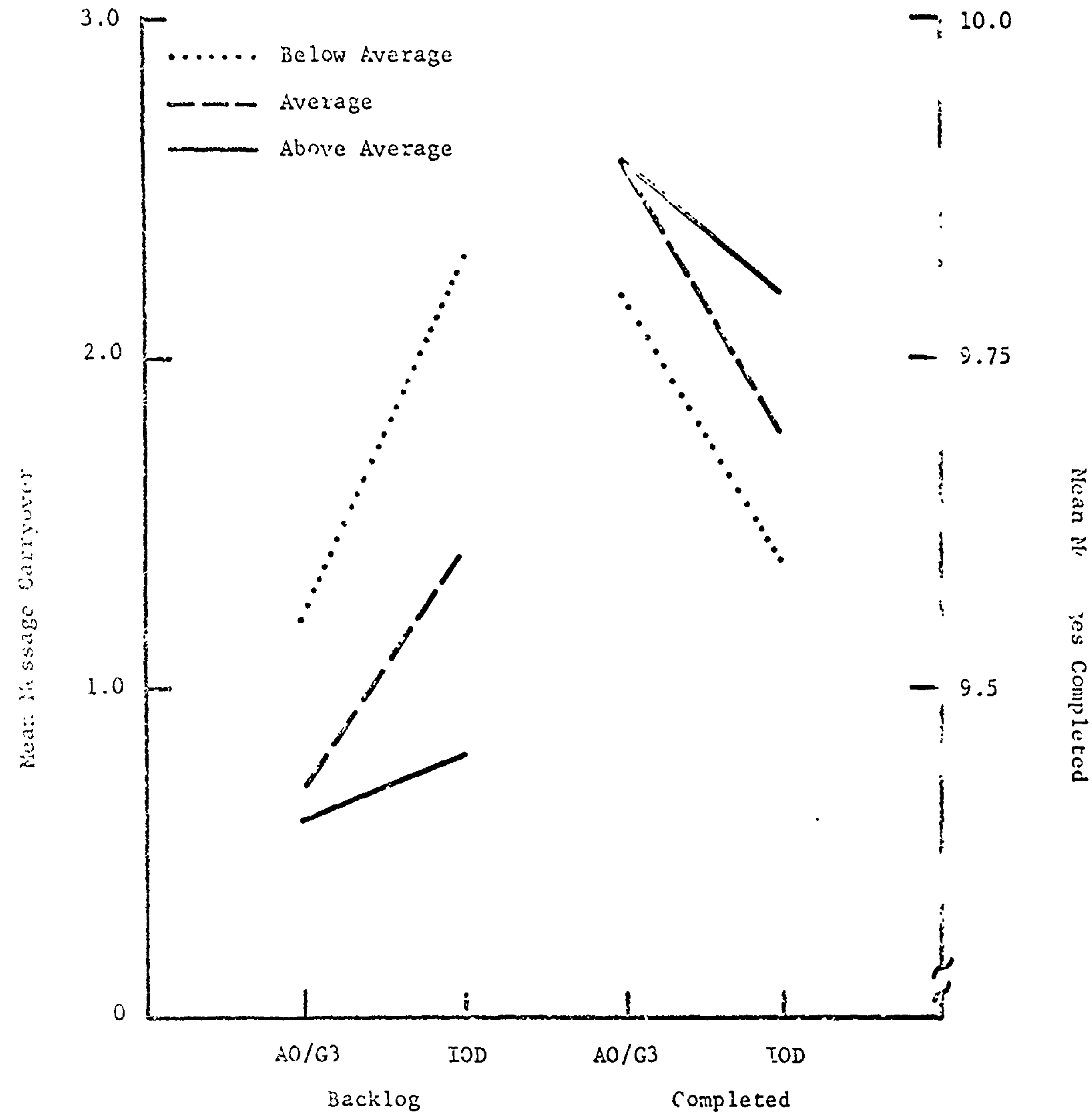

Figure 3-4. Mean number of messages carried over and completed as a function of operator skill level.

Operator Errors

Results which show the effect of operator skill level on the mean number of undetected errors for each message type were also obtained. For error type 1 (errors of commission), the simulated above average skill level operators showed a mean of 11.61 per message while a mean of 12.06 was indicated for the average operators, and a mean of 12.28 was indicated for the below average operators. In the case of the type 2 errors (errors of typography, spacing, or abbreviation), a mean of 7.49 was indicated for the simulated above average skill level operators, while the indicated means for the simulated average and below average teams were 7.56 and 7.68 respectively. Errors of type 3 (omission) followed the same pattern, with the operator skill levels I, II, and III producing 11.7, 12.13, and 12.36 errors per message respectively.

These results seem intuitively in the correct direction and the sensitivity of this output to skill level variation seems supported.

For error returns, however, no discernible trend due to operator skill level was suggested by the simulation results. The above average operators had 3.67 error returns per message, as compared with 3.70 for the average operators, and with 3.68 for the below average skill level simulated operators. We note that within the internal logic of the model logic, as discussed in the previous chapter, operator skill level exerts no direct effect on the number of undetected errors produced. For task elements identified as those which may produce undetected errors, only the message type and the probability of the undetected error are used as input to the random number generator in which the actual number of undetected errors is determined. However, operator skill level exerts an indirect influence on undetected errors because operator skill level does determine how many times a task element will be failed, and the number of times a failed task element is repeated will affect the total number of errors produced.

Effects of Operator Mix

In all of the sensitivity tests, the number of crew members simulated was held constant at six. In all the runs discussed previously, the six crew members consisted of two action officers, the G-3, and three UIOD's. In this section, the effects on model output of changing the operator mix to one action officer, one G-3, and four UIOD operators will be presented and discussed. These two operator mixes will be referred to henceforth as 3/3 and 2/4, where the first number of each pair represents the number of action officers including the G-3, and the second identifies the number of UIOD operators.

Time Worked

Figure 3-5 shows the effects of operator mix on the percentage of time worked. The vertical axis shows the percentage of time worked, while the horizontal axis shows the operator skill levels.

When the 2/4 mix was involved, the action officers were indicated to be very busy (top plot). This mix has one action officer and one G-3 handling the same workload as is being handled by two action officers and the G-3 in the 3/3 mix. As a result, at all action officer skill levels, the action officer was indicated by the model to work longer in order to process the message load. These directional tendencies seem in accord with logic.

For the UIOD operators, however, the effects due to the operator mix was not as great. The increase of one UIOD operator in the 2/4 mix from the 3/3 mix was indicated to make only a 6 to 17 per cent difference in the amount of time worked, as compared to a 27 to 42 per cent difference in the time worked for the action officers. The model suggests that the 3/3 operator mix yields a more even load balance between action officers and the UIOD operators.

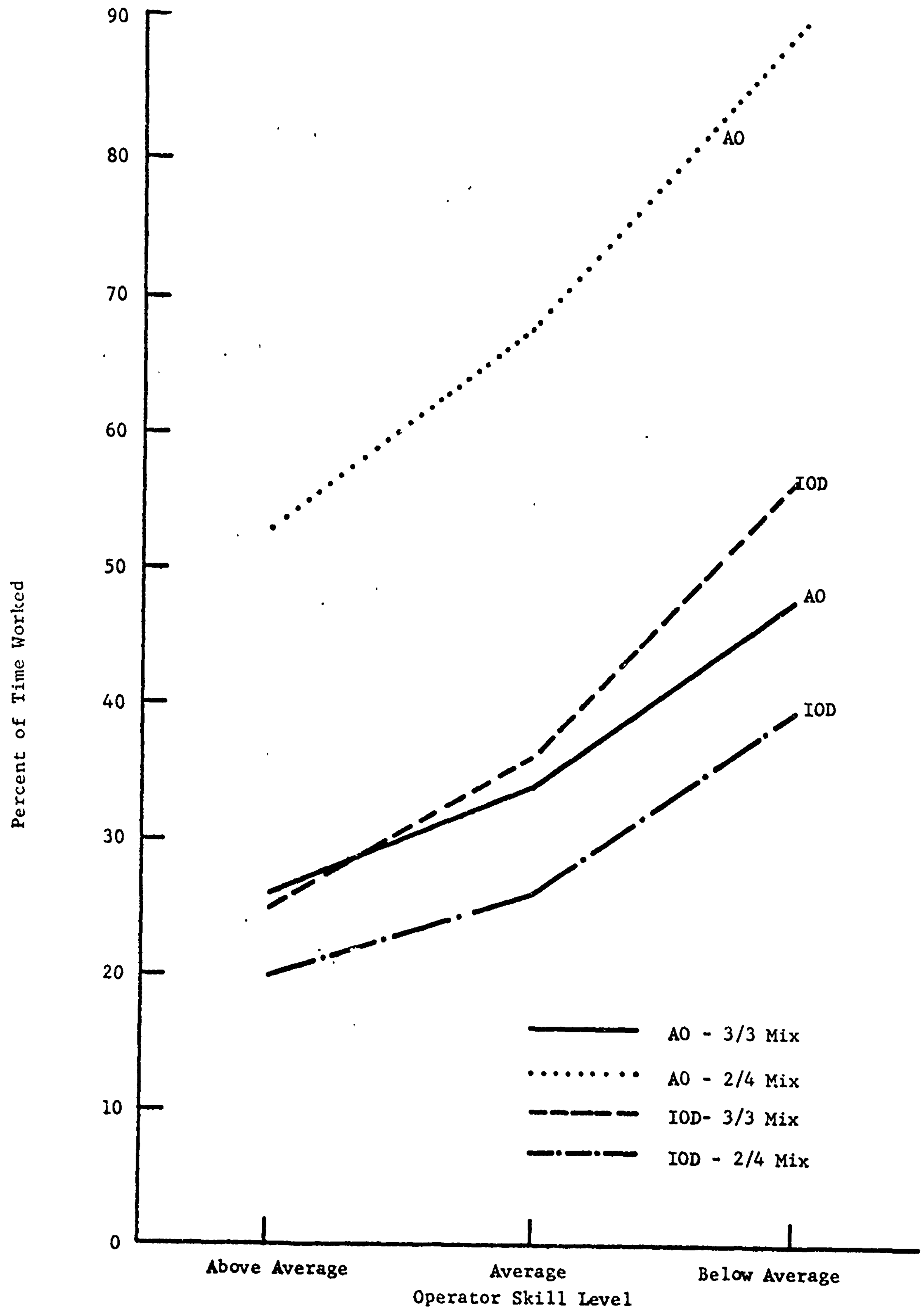

Figure 3-5. Effect of operator mix on percentage of time worked.

The difference between the two operator mixes is interactive with the effect of operator skill levels. At the above average skill level, the difference between the two mixes in time worked was 27 per cent for the action officers and 5 per cent for the UIOD operators, while at the below average operator skill level, the difference was 42 per cent for the action officers and 17 per cent for the UIOD's .

The directional expectancy of about a 33 per cent decrease in time worked as the result of the addition of a third UIOD operator is confirmed by these results (6/20 + 10/26 + 17/40 = .35). The same result would not be anticipated by the addition of one action officer to the two man G-3 action officer complement. Within the logic of the model, the G-3 only enters into the message processing when: (1) a queue exists, (2) the action officer is busy, and (3) the priority of the message to be processed is 1. In this case, we would expect, on the average, almost a 50 per cent effect on action officer time worked as the result of the manning increase. Such a result was, in fact, indicated by the model (27/53 + 33/68 + 42/90 = .47). Hence, within the limits of this particular test, the model's output seems sensitive and rational.

Time Used by Time Segment

Figure 3-6 shows the effect of operator mix on the time used in each of the five message processing segments in message completion for the simulated average operators. The primary difference between the two operator mixes can be seen in time segment 1. Time segment 1 represents waiting time for the message until the action officer starts to process it. In the 3/3 mix, the mean waiting time was 48 seconds, while for the 2/4 mix 211 seconds were consumed. This result is concordant with the prior indication of greater working time for the action officer in the 2/4 mix.

In time segment 4, which represents waiting time in the UIOD operator's queue, only 13 seconds were consumed in the 2/4 mix, as compared to 26 seconds in the 3/3 mix. The other time segments are in close correspondence across the two mixes, and it would not be anticipated that the manning level would influence these time segments. These time segments are concerned with actual message handling time which would be constant regardless of manning level.

Accordingly, it seems that the model's output appropriately reflects manning level differences for the time segments as for the total indicated time worked.

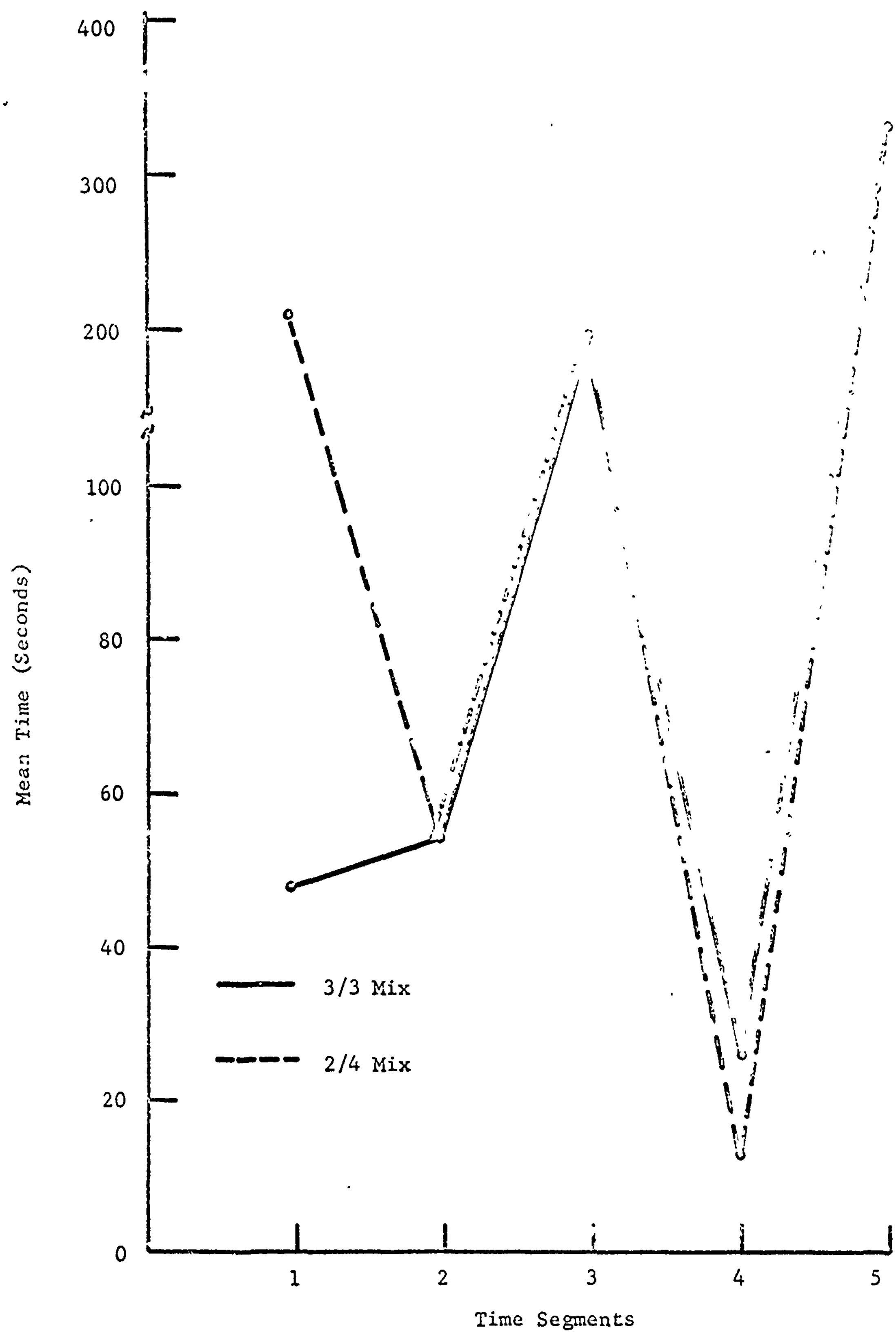

Figure 3-6. Time used in time segments as a function of operator mix.

Effect of Operator Mix on Work Performance

Table 3-3 shows the indicated effects of operator mix on messages completed and on messages carried over for each hour by the simulated average team. The simulated AO/G-3 in the 3/3 operator mix were indicated by the TOS model to carry over .7 message per hour, while the AO/G-3 in the 2/4 operator mix were indicated to carry over 1.2 messages. The TOS model indicated the UIOD operators in the 3/3 operator mix to carry over 1.4 messages on the average, while the UIOD operators in the 2/4 mix were indicated to carry over 1.3 messages. Both results are in the predicted direction.

Table 3-3

Effects of Operator Mix on Messages Completed and Carried Over Per Hour

Operator Mix	Carried Over AO/G-3	Carried Over IOD	Completed AO/G-3	Completed IOD
3/3	.7	1.4	9.9	9.7
2/4	1.2	1.3	9.8	9.7

The AO/G-3's in the 3/3 mix carried over fewer messages because there are more AO's to handle the same message workload. The UIOD's in the 2/4 operator mix carried over fewer messages for the same reason.

Effects of Message Workload

Three levels of hourly message workload were simulated: [illegible], [illegible], or 15 messages per hour. Figure 3-7 shows the effect of each message workload on the percentage of time worked by action officers and by UIOD's. The data presented in Figure 3-7 are based on the simulated average skill level team and the message arrival distribution was 80 per cent random over the entire hour, with 20 per cent of the total messages arriving randomly in the last quarter of the hour. As a consequence, message density was greatest in the last quarter hour.

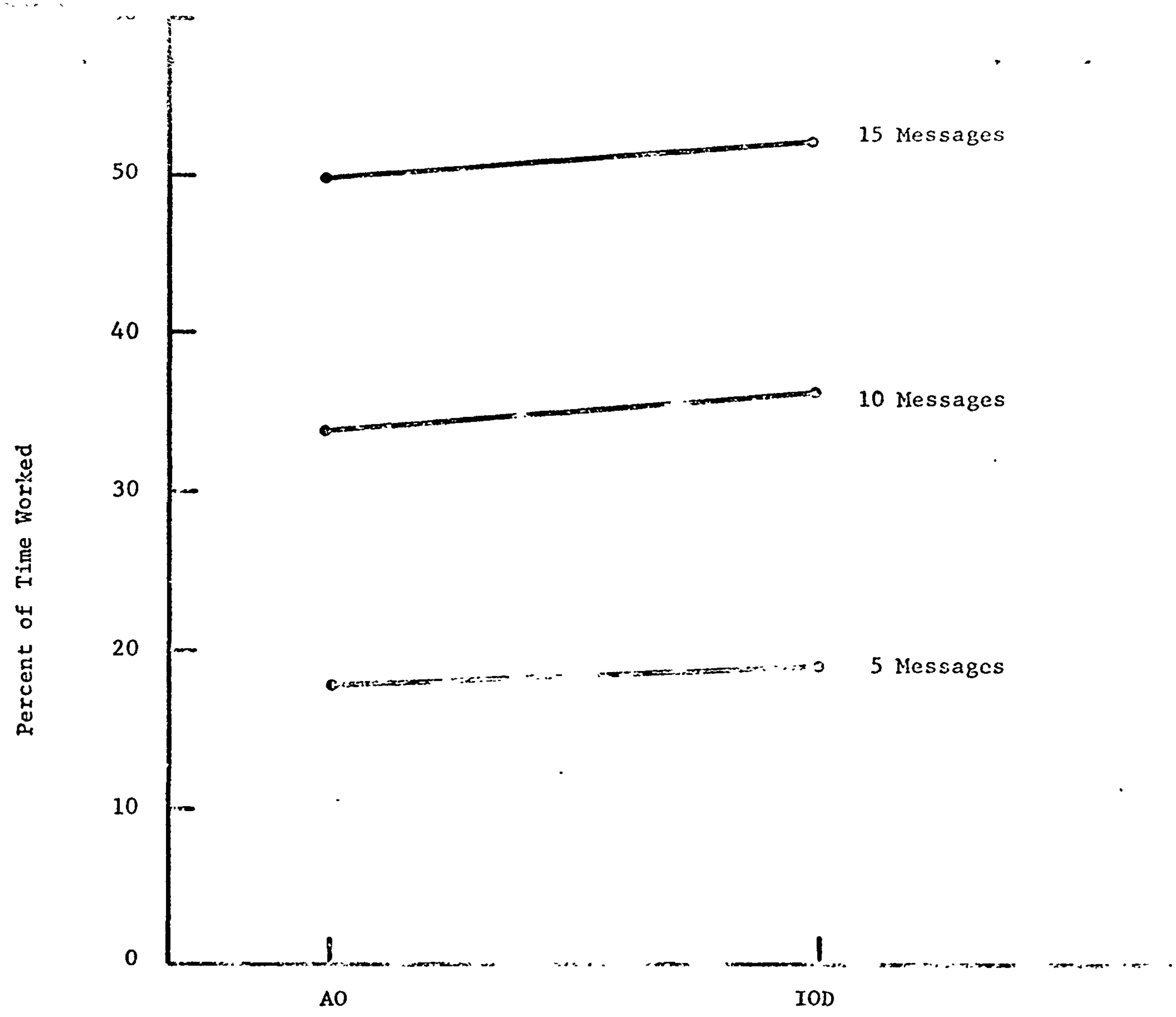

Figure 3-7. Effect of message workload on percentage of time worked for AO/G-3 and for UIOD.

As indicated by Figure 3-7, the simulation model seems sufficiently sensitive to the effects of message workload and yielded results in the anticipated direction.

Figure 3-8 shows the effect of message workload on mean time used in each time segment. The total times for message completion were 640 seconds for the 5 messages per hour rate, 658 seconds for the 10 messages per hour rate, and 700 seconds for the 15 messages per hour group. Clearly, the mean processing time per message increased as the workload increased. Figure 3-8 allows us to identify where the increased message processing time occurred. In time segment 1 (action officer queue time), the five message workload required an average of 20 seconds, while the 10 message workload required an average wait of over twice as much--44 seconds. The 15 message group requires even more time, a mean of 80 seconds.

Time segments 2 and 3 show negligible differences between the message workloads, but time segment 4 (UIOD queue time) shows the same clear trend as did time segment 1. The five message workload resulted in an average of 10 seconds in time segment 4, the 10 message workload produced 26 seconds in this segment, and the 15 message workload required 51 seconds. Since time segments 1 and 4 are message queue (waiting) times, this result indicates, as would be expected, that queue times increase as the frequency of messages increase, but that once a message processing has begun, little, if any, difference is noted.

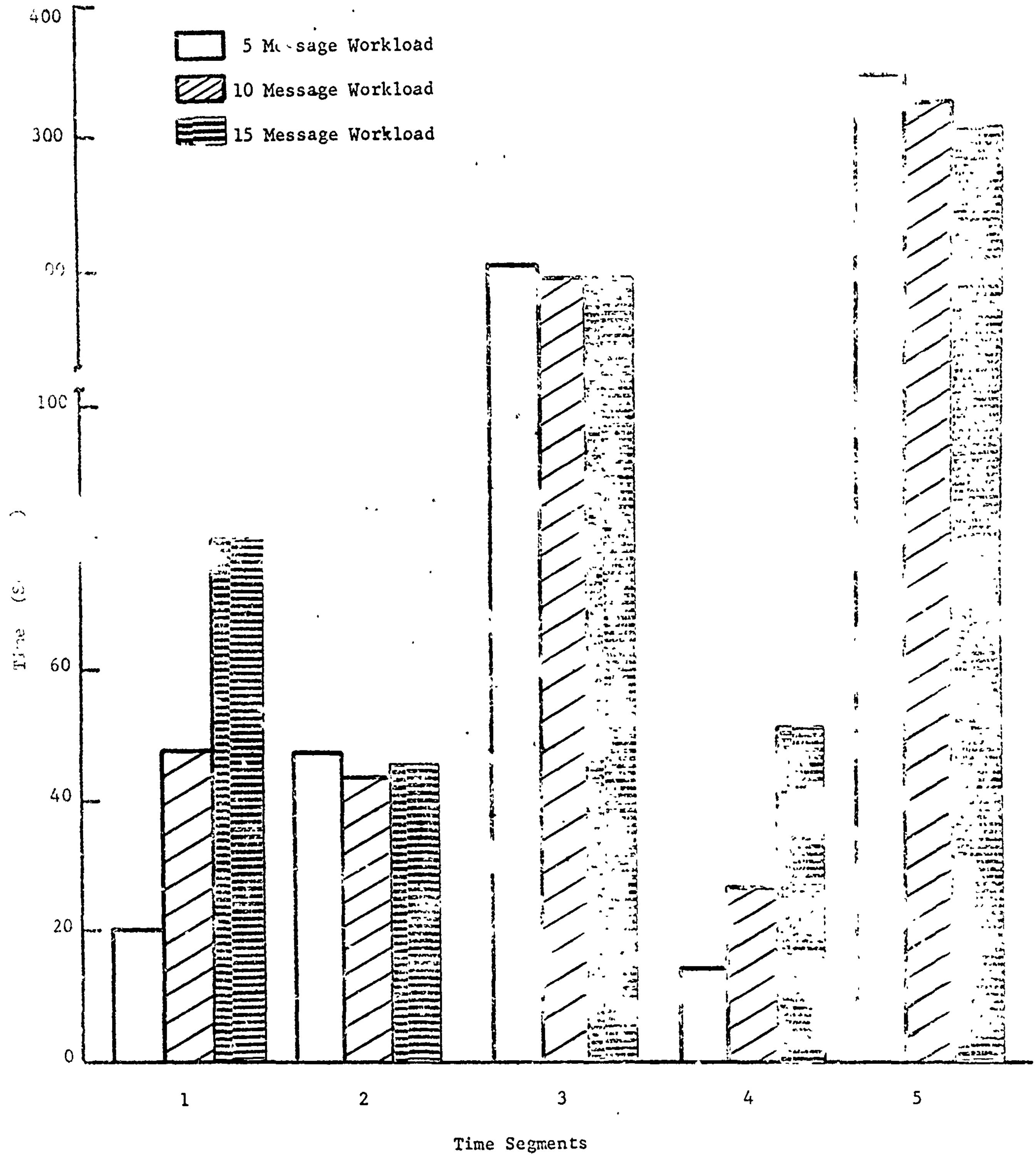

Figure 3-8. Effect of message workload on message processing time segments.

Additional Tests

Finally, a series of computations was performed on certain aspects of the internal logic of the model to depict certain selected model functions. These tests were performed prior to programming as an independent check of the reasonableness of these relationships as incorporated in the TOS model.

Figure 3-9 shows the effect of aspiration (ASP) on performance adjustment (PAFA) as a function of present performance (PERF) when the performance level is less than the aspiration level and the stress level is less than the stress threshold. Under these conditions, decreased performance times will occur as the operator attempts to bring his performance in line with his aspiration. The larger the difference between the aspiration level and the performance level, the smaller will be PAFA. Since PAFA is a value which is multiplied by mean time required, the simulated time to perform task elements becomes faster as PAFA decreases. To take an extreme case, if aspiration is 1.00 and performance is .65, the performance adjustment factor will be 0.86. If performance were 0.75, the adjustment factor would be .89--assuming the aspiration level to be 1.0. Aspiration has a maximum value of 1.0 (i.e., perfection), as do performance level and the performance adjustment factor.

Figure 3-10 presents the simulated time used, V, as average time is shown to vary through its probable range. The solid lines show the range which includes 50 per cent of all values, while the dotted lines shows 99 per cent of all values. This figure shows that the larger the standard deviation (SIGMA), as a percentage of the mean, the wider will be the range of V values which can be expected. Within this logic, the output time, V, is multiplied by the adjustment factors for operator speed, aspiration, and fatigue to produce the final simulated performance time.

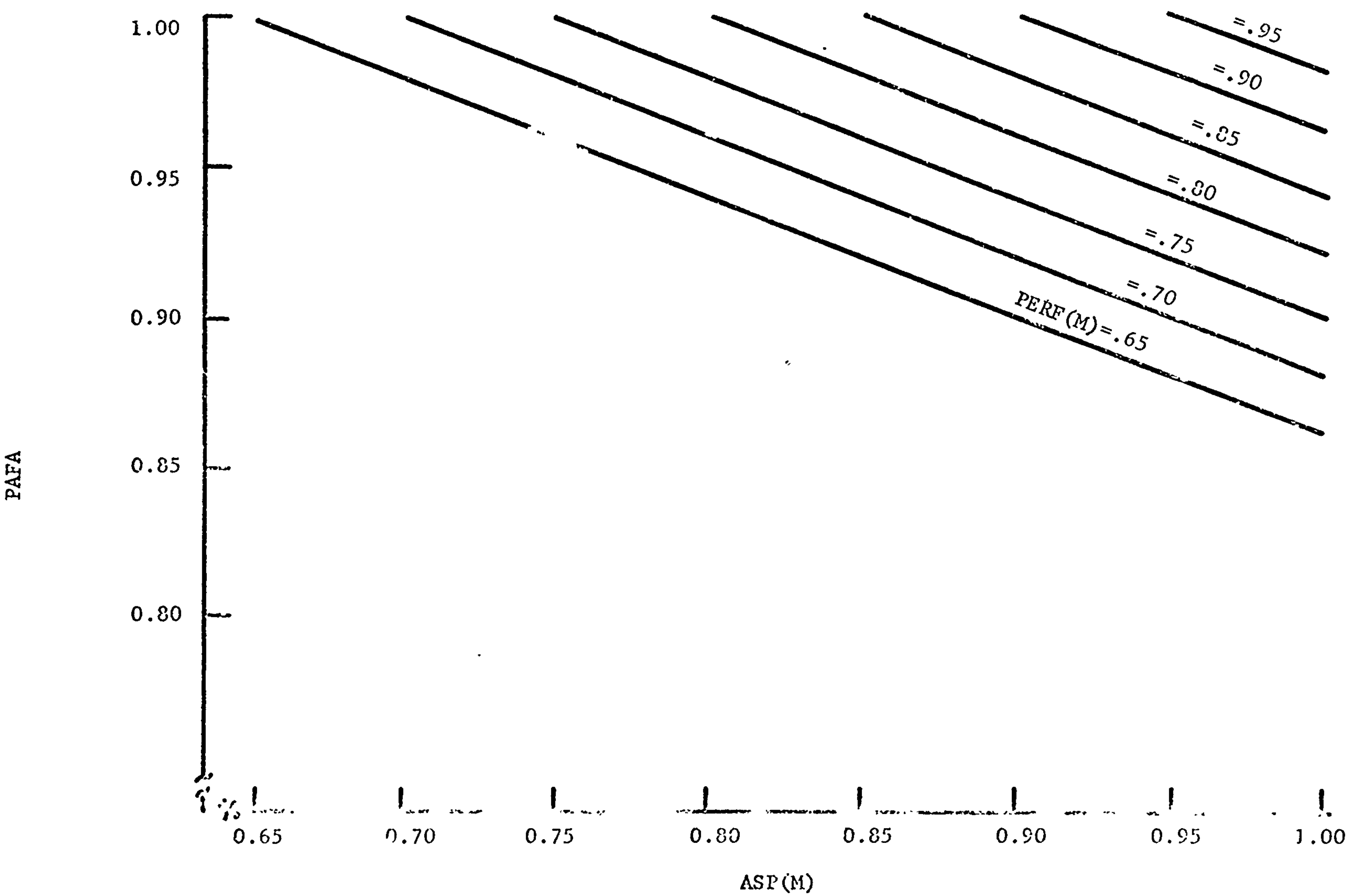

Figure 3-9. The effects of aspiration and performance upon PAFA when PERF(M) < ASP(M), STR(L) < STR(M) and K=0.4.

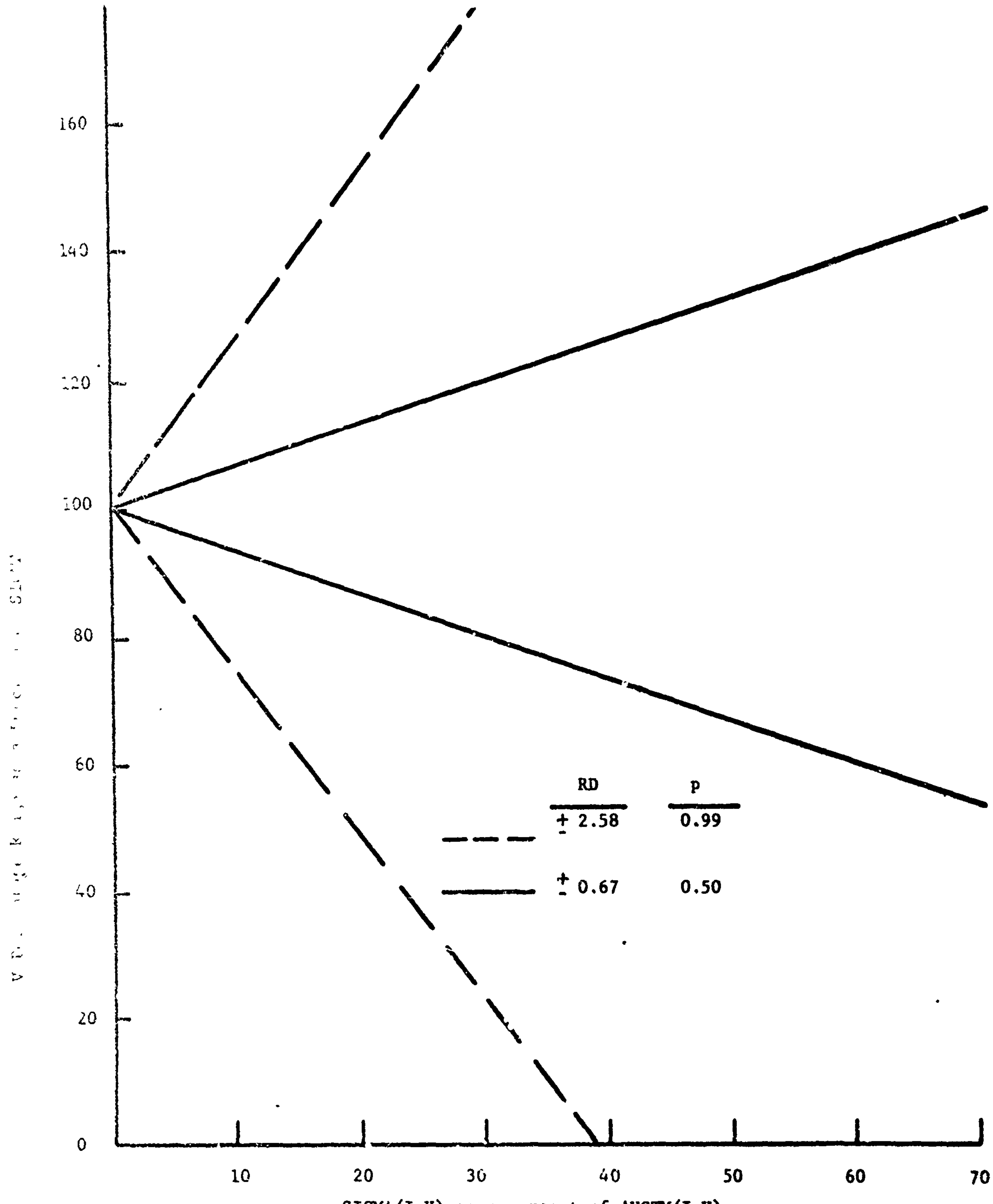

Figure 3-10. The effects of SIGMA(I,K) and RD on V at probability level of 1.0 and 2.50 in the equation V = AVGTM(I,K) + RD [SIGMA(I,K)] .

Figure 3-11 shows the result of simultaneous variation of four factors on percentage change from average time, AVGTM(I, K). The four factors involved are operator speed, F(M), adjustment factor for aspiration, PAFA, adjustment factor for work, PAFW, and the stress factor, SF = (STR-1)/(STRM-1). The variable V is held equal to 1. Three levels of the operator speed (1.0, 1.1, and 0.9) are shown, where 1.0 represents the "nominal" case. The corresponding three levels of PAFA shown are 1.00 for the nominal case, 1.05 for the high, and 0.95 for the low. The three levels of PAFW are: 1.02 (nominal), 1.17 (high), and 1.00 (low).

As the stress factor goes from zero to 0.9, all three curves--nominal, high, and low--drop quite fast initially. Then, the rate is decreased as the higher stress factor levels are reached.

Thus, in the extreme case, performance time would be reduced to about one-third of its average input value for a fast operator who also receives a further impetus due to his aspiration.

The TOS model's logic calls for an increase in aspiration level whenever performance is greater than aspiration and stress is less than the stress threshold. Aspiration may be increased to a maximum of 10 per cent of the difference between performance level and the present aspiration level. The exact level of increment between zero and 10 per cent is determined by use of a uniformly distributed random number, RY. Figure 3-12 shows graphically the range of increments when the performance levels are 1.0 and 0.8. For example, if present aspiration is 0.6 and performance is 1.0, the aspiration may be raised as high as .64 or not be changed at all, depending on the random number which occurs. If performance was 0.8 while aspiration was 0.6, aspiration might be increased to .62. The shaded part of the curve identifies the permissible range of increment for PERF(M) equals to .8, while the 1.0 performance level includes the shaded area plus the unshaded enclosed area. Note that the shaded area is shown only for ASP(M) values less than 0.8. This is reasonable since the equation constraints require performance to be greater than aspiration.

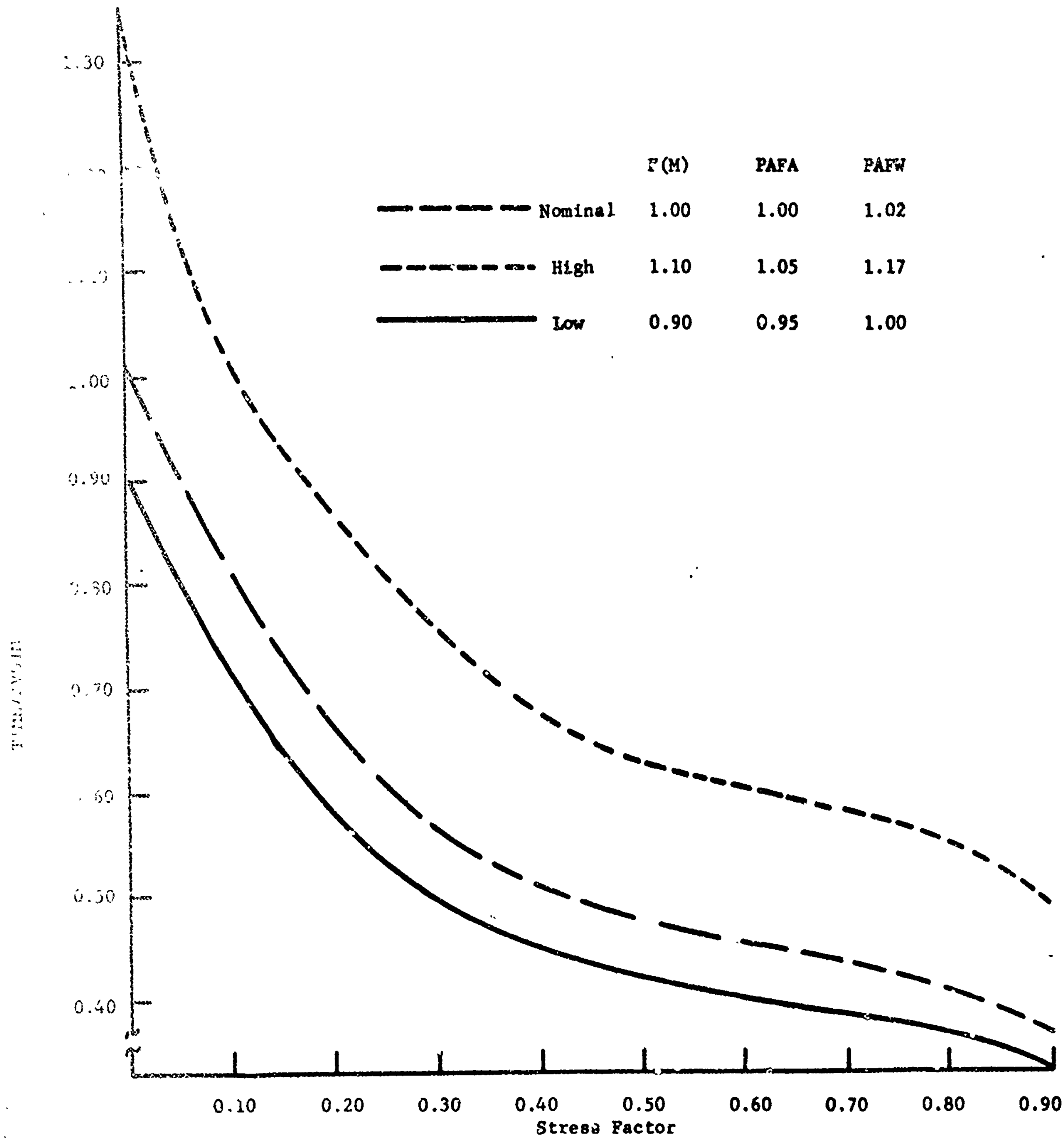

Figure 3-11. The effect on time of stress when F(M), PAFA, and PAFW assume high, low and nominal values but V = 1.

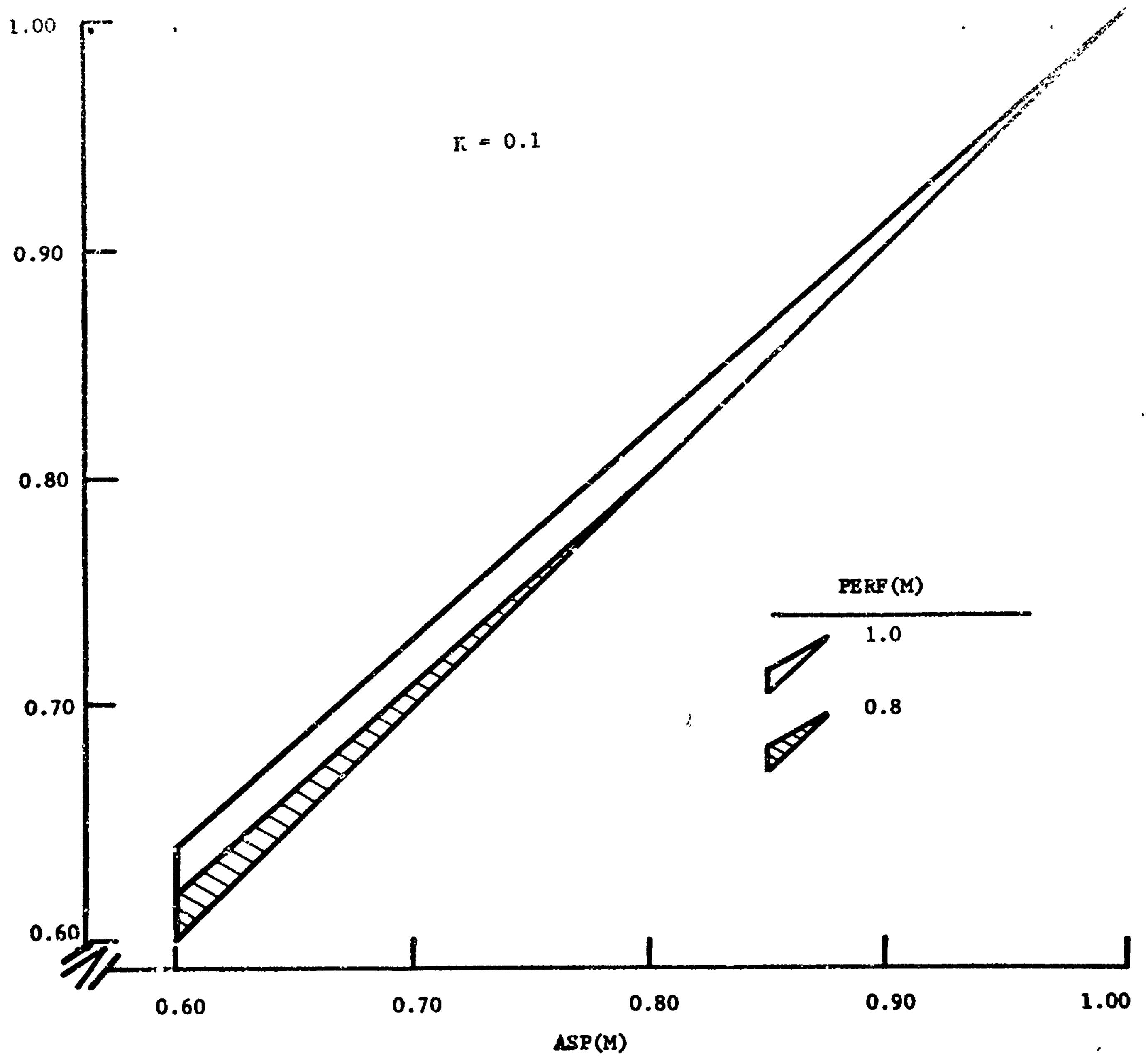

Figure 3-12. The ranges of variation produced in subsequent aspiration by variations in aspiration, performance, and the equiprobable random distribution, when PERF(M) $\geq$,ASP(M) ,STR(M) < STRM(M) ,0 < RY < 1 and K = 0.10 in the equation ASP(M)' = ASP(M) + K [PERF(M) - ASP(M)] RY

Figures 3-13 and 3-14 are similar to Figure 3-12, except for different limits of adjustment, K. Figure 3-13 shows the effect when the maximum adjustment is 5 per cent of the difference between performance and aspiration, and Figure 3-14 shows the effect where 20 per cent of this difference is used as the maximum. A comparison of these three graphs shows that a maximum of 5 per cent (as in Figure 3-13) products only a slight percentage change in ASP(M). This would seem to be an inconsequential and meaningless adjustment. Figure 3-14, on the other hand, with a maximum adjustment of 20 per cent, shows a much larger effect. However, this adjustment appears too large for realistic simulation of this effect on performance. The adjustment shown in Figure 3-12 (K = 1) is the one incorporated into the model's logic. This effect seems large enough to exert a meaningful role on the simulation without overbalancing the aspiration effect.

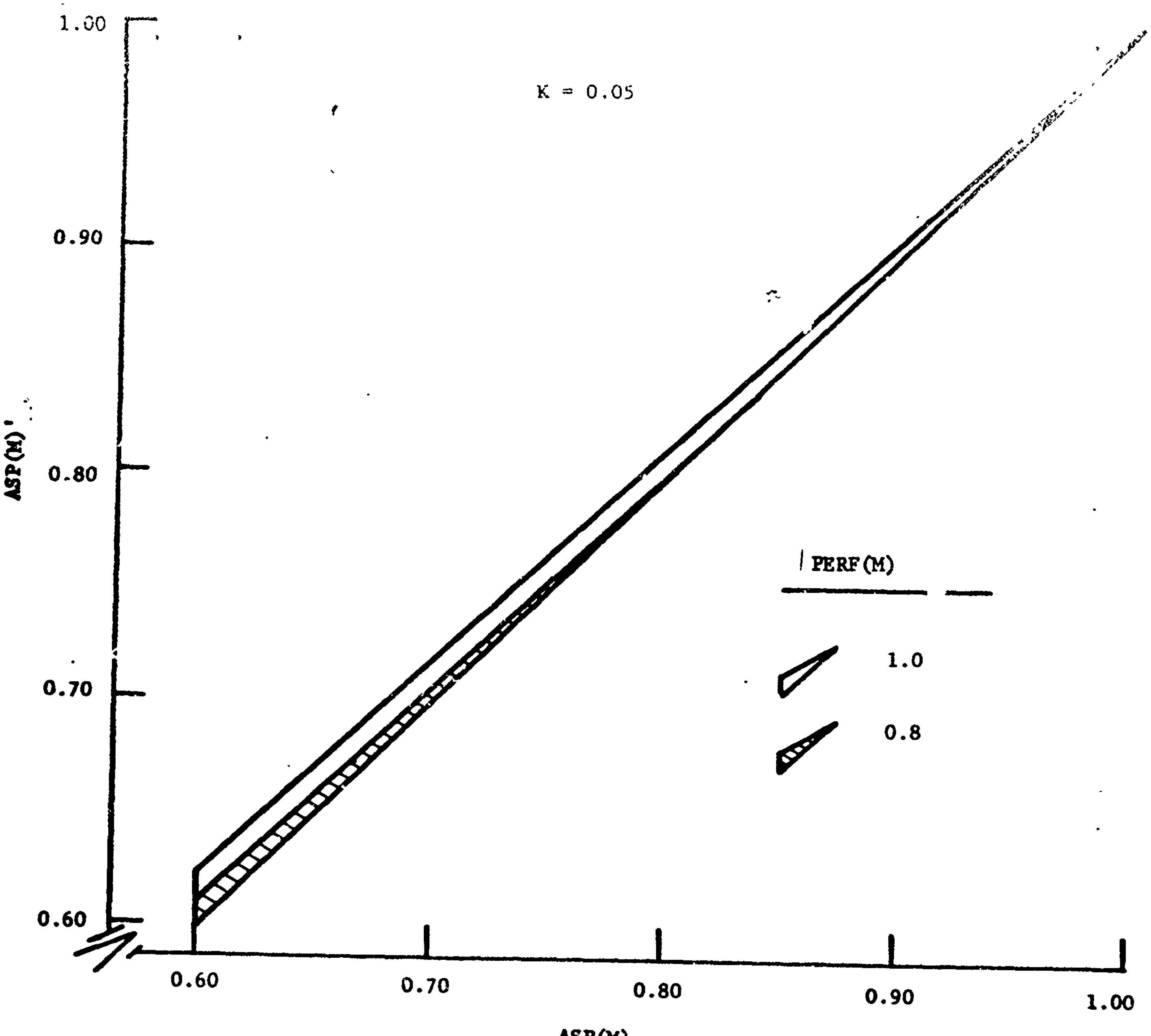

Figure 3-13. The ranges of variation produced in subsequent aspiration by variations in aspiration, performance, and the equiprobable random distribution, when PERF(M) ≥ ,ASP(M) ,STR(M) < STRM(M) ,0 < RY < 1 and K = 0.05 in the equation ASP(M)' = ASP(M) + K [PERF(M) - ASP(M)] RY.

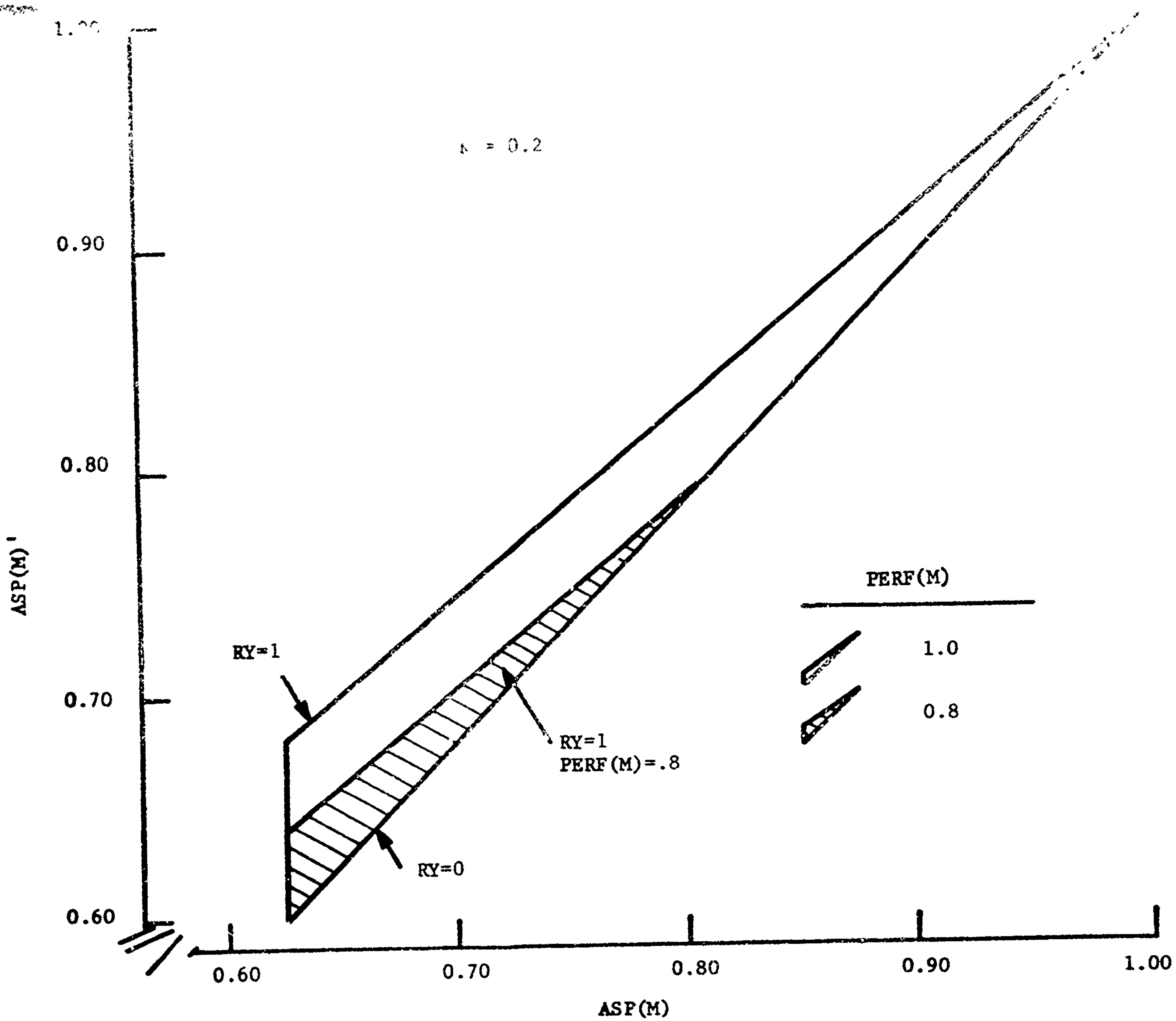

Figure 3-14. The ranges of variation produced in subsequent aspiration by variations in aspiration, performance, and the equiprobable random distribution, when PERF(M) ≥ ,ASP(M), STR(M) STRM(M), $0 < RY < 1$, and $K = 0.20$ in the equation $ASP(M)' = ASP(M) + K\,[PERF(M) - ASP(M)]\,RY$

CHAPTER IV

DISCUSSION, SUMMARY, AND CONCLUSIONS

The prior chapters of the present report have described the logic and steps involved in the development of a stochastic digital simulation model which possesses the goal of simulating the message handling within the TOS. The sensitivity of the model's output to variation of such parameters as operator skill, message load, and manning mix were also described.

In its present state of development, it seems that the TOS model shows sufficient merit to warrant further investigation of the agreement of the model's output with the actual TOS performance. We do not hold that the predictive validity of a model represents a single qualifying characteristic. The degree of predictive validity required in a model will vary, among other things, with the intended use of the model. For some uses, simple prediction of hierarchical ordering of alternatives may be sufficient. In other cases, a higher order of scaling may be required. Chapanis (1961) has also commented on employing validity as a sole criterion for judging model adequacy. Chapanis distinguished between models and theories and stated that "models are judged on the basis of utility; theories are judged on the basis of validity."

Nevertheless, an initial test of the concurrent validity of the TOS model has, in fact, been completed. In this test, TOS model outputs were compared with the findings from a set of physical simulations of the performance of operators in the TOS system. In the actual physical simulations message handling was varied in two alternative ways: (1) transform operations completed by an action officer who then gives the transformed message to an operator for insertion into the information system by way of the UIOD, and (2) action officer not only performs the transform operation, but also performs the operations concerned with direct message input on the UIOD.

The results of this introductory validational study are presented in Tables 4-1 and 4-2. Table 4-1 compares the error data predicted by the computer model and that produced in the independent experiment (criterion data). Table 4-1 indicates remarkably close agreement between the total percentage of errors predicted (14.1) and the criterion data (12.3). Close agreement is also shown for each type of error tested. Table 4-2 presents a summary of the time to complete the various portions of the work sequence as predicted by the computer model and as measured in the actual experimental simulation. There is no entry in the paper format

cell of Table 4-2 since in the "on-line" condition this step is obviously omitted. The remaining entries in Table 4-2 indicate remarkably close agreement between the model's predictions and the criterion measurements.

Table 4-1

Comparison of Model's Predictions of Errors with Experimental Data

	Omission	Commission Typographic (proportion)		Incorrect	Total (per cent)
One Man On-Line					
criterion	.033	.018	.044	.028	12.3
computer model	.026	.020	.055	.040	14.1
Two Man TOS					
criterion	.053	.015	.095	.029	19.2
computer model	.055	.014	.098	.025	19.2

Table 4-2

Comparison of Model's Predictions with Criterion Data for Time (Sec.) to Perform Various Acts

	Paper Format	CRT	Total
One Man On-Line			
criter	———	374	374
computer model	———	380	380
per cent difference	———	+ 1.6%	+ 1.6%
Two Man TOS			
criterion	269	187	456
computer model	283	183	466
per cent difference	+ 5.2%	- 2.1%	+ 2.2%

This is not to say, however, that reexamination and calibration of certain of the model's internal constructs are not indicated. The need for reexamination of the efficiency calculation was indicated in Chapter IV of this report. Other model constructs which might be reexamined are presented, along with the associated rationale, below:

1. Extension of effects of precision--Currently operator precision directly affects operator success probability but does not affect the number of operator errors. Logic revision seems indicated to allow precision to affect both success probability and errors. Accordingly, model revision to allow this feature may be indicated.

2. Reexamination of task element success calculation--Currently stress directly affects task element success probability and operator aspiration in accordance with the level of stress on the operator. However, for a given stress level, the simulated effect is the same regardless of the length of time the operator has been influenced by the stress. This logic should be modified so as to allow a differential effect of stress as a function of the time that an operator has been under stress.

3. Extension of number of installations considered--Currently only one TOS installation may be simulated in any simulation run. It seems possible that the logic and associated programming should be extended to allow simultaneous consideration of multiple installations and their interaction. This would allow a more realistic simulation of the total TOS with little or no sacrifice in simulation accuracy or computer running time, if only one installation is simulated.

4. Revision of action officer output--The present logic generates one action officer output message for each incoming message. However, it is believed that in some cases there may be more than one action officer output message for an individual incoming message. Logic and program revision may be required in order to accomplish this aspect of simulation of TOS procedures.

5. Revision of stress function--Stress is now calculated as a function of queue length without consideration of the priority of the messages within the queue. Consideration should be given to the value of calculating stress as a function of the number of messages in the queue appropriately weighted by their priorities. If indicated, the logic and programming should be revised to reflect this logic.

6. Extension of shift limit capacity--As currently programmed, the model simulates, hour by hour, the work of a 12 hour shift. Extension of this capacity is suggested to allow simulation of a 24 hour day with: two shifts of 12 hours each, three shifts of eight hours each, four shifts of six hours each, six shifts of four hours each.

Additionally, it seems that the sensitivity testing of the model should be extended to include a greater range of parametric variation than that included in this introductory study.

Nonetheless the TOS model, as developed to date, seems to have met adequately most of the tests which can be applied during the initial developmental stages of a digital simulation model. Mayberry (1971) defines a valid model as "one in which we have ernestly sought, and failed to find, a single disqualifying defect." While we do not hold that the TOS model possesses no defects, we do hold that none of its defects are of such a nature as to warrant its disqualification. Mayberry also describes a set of criteria which should be held in mind when considering the adequacy of a model. These are symmetry, continuity, indifference to trivial aggregation, correct behavior in the limit, correct direction of change, and physical dimension congruence. The final criterion, physical dimension congruence, is not appropriate to the TOS constructs, except possibly the message unit dimension. It can be demonstrated that the tests of the TOS model completed to date meet all but one of the Mayberry criteria. The criterion which we have not met is correct behavior in the limit. And this is so only because we have not tested the TOS models at its limits.

Accordingly, it seems that the present TOS model can be considered to represent a useful tool which possesses significant potential for simulating the effects of varying personnel, manning, and system operational characteristics on actual TOS performance.

Summary

The TOS model allows digital simulation of the effects of such variables as message queuing, detailed message processing procedure, error rates, and personnel characteristics, along with stochastic variations, to yield predictions of actual TOS performance. Parameters which may be varied to study their impact on system performance include:

- hours per shift
- number of actions officers
- number of UIOD operators
- operator fatigue
- error rates (per hour, per type of error, per type of message)
- personnel characteristics (4 variables)
- message arrival frequency
- message workload
- message type mix
- message length
- message handling procedure

The program allows for detailed message processing, hourly summary, shift summary, and run summary output opinions. The detailed message processing output shows the fine grain of the results of the simulation of an action officer's selection and formating, followed by UIOD operator processing, of the messages which arrive each hour of a shift.

The hourly summary presents a consolidation of the results of a simulated hour's work and includes items such as: number of messages completed, number of messages rejected, number of messages unprocessed, time spent working, end of hour stress level, end of hour level of aspiration, time spent performing various processes, average time per message, errors, and information loss.

The shift summary, produced at the conclusion of one n hour shift provides a consolidation of certain information derived at the end of each hour, e.g., total messages processed, time worked, overall effectiveness, errors.

The simulation run summary, produced after N simulations of the same shift, consists of five parts--manpower utilization, message processing time, overall efficiency indicator, workload summary, and error summary. The manpower utilization summary shows the mean time each man worked for each of the simulated hours, the mean amount of time each man spent on a message by each hour, and the final stress and aspiration levels of each man. The message processing time summary shows by message type, priority, and hour the amount of time spent in each of five time segments. The efficiency components--thoroughness, completeness, responsiveness and accuracy, as well as overall efficiency--are also shown for each simulated hour. The run workload summary contains the mean number of arriving messages which were completed or carried over during each simulated hour, as well as the number of rejected or interrupted messages.

The error summary shows the mean number of errors of various types (i.e., omission, abbreviation/typographic/spacing, or commission) for each hour and for each message type.

Specifically, on the basis of input data, the model generates a message workload for the first hour of a shift for the simulated TOS personnel. It assigns priorities and other characteristics to the simulated message and forms a message queue. Then, the simulation of the processing of these messages by the action officer and UIOD personnel takes place to yield the hourly output record, as described above. When the simulation is completed for the first hour of the shift, a message workload is generated for the second hour. Messages which were carried over from the first hour are added to this second hour workload,

and the simulation of the processing for the second hour of the shift takes place. An hourly summary for the second hour is then produced. This procedure continues until the total shift has been simulated at which point a summary for the shift is produced.

Due to the stochastic nature of many of the simulation aspects, a number of repetitions is required to produce a stable result. Repetitions of a simulation with the same set of input variable conditions is called a run. At the conclusion of a run, the run summary, described above, is produced.

The end result is the ability to answer questions such as:

1. How does system effectiveness vary as a function of message load?

2. How does system effectiveness vary as a function of message arrival time distribution?

3. How does system effectiveness vary as a function of personnel proficiency?

4. What is the effect of increasing or decreasing the manning level or personnel proficiency?

5. How much stress was on the operators during the performance of the work of each hour?

6. How does system effectiveness vary as a function of operator level of aspiration?

7. What is the error rate for various message types and for various mannings and personnel attributes within manning?

8. How much time was spent, on the average, processing each type of message?

9. How much time was spent, on the average, for each type of message in performing acts such as: message screen, message transform, transformed message input?

10. How many error returns were involved for each type of message?

11. What is the success rate?

12. How effective was the work in terms of the following four criteria: accuracy, thoroughness, responsiveness, and completeness?

Conclusions

On the basis of the materials presented in prior sections of the present report, the following conclusions seem indicated:

1. A stochastic digital simulation model for simulating human performance in TOS operation has been developed, programmed, and implemented.

2. The model seems to yield outputs which are consistent with logical expectancy, and to be sensitive to variation in the parameters considered.

3. Some reexamination and extension of certain of the model's internal constructs and certain output measures, along with additive sensitivity testing may be indicated.

4. The Behavioral and Systems Research Laboratory now has a tool which possesses significant potential for simulating, via digital computer methods, the effects of varying personnel, manning, and system operational characteristics on actual TOS performance.

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APPENDIX A

TOS Model User's Model

This appendix presents the information required by the user of TOS simulation model in preparing his data for the computer and in running the TOS model. Included are the card input formats, card sequences, variables and subscript lists, and the like. The program is written in the FORTRAN IV language for implementation on the CDC 3600 digital computer.

Principal Subscripts

Table A-1 shows the principal FORTRAN subscripts used for indexing computer dimensioned variables. For each FORTRAN subscript, the actual variable name and present maximum value is shown. Without computer program changes, the computer model cannot handle cases where the variables exceed these maximum values. These subscripts are also used in some cases as variables in their own right.

Also included here are the assignments for the 5 priority codes (IP), 2 operator type codes (J), 4 effectiveness components (NEC), 6 man number assignments (M), 4 error typetype codes (IE), and 7 message type codes (IT).

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Table A-1

Principal Model Subscript Variables

Variable	Subscript FORTRAN	Maximum Value	Maximum Value FORTRAN
Hour Number	IH	15	IHMAX
Iteration Number	NSHF	100	NSHIFT
Message Number (Cumulative)	CMSG	200	
Priority Number	IP	5	
1 - routine			
2 - priority			
3 - operational immediate			
4 - flash			
5 - presidential interrupt			
Task Element Number	I	20	
Task Analysis Number	K	4	
Operator Type	J	2	
1 - G3 and Action Officer			
2 - IOD			
Effectiveness Component Number	NEC	4	
1 - thoroughness			
2 - completeness			
3 - responsiveness			
4 - accuracy			
Man Number	M	6	MEN(3)
MEN(1) : Action Officers & G3s (G3 is MEN(1))			
MEN(2) : IOD operators			
Error Type	IE	4	
1 - commission			
2 - typographic (includes abbreviation & spacing)			
3 - omission			
4 - other			
Message Type	IT	8	
1 - add data			
2 - change data			
3 - delete data			
4 - query			
5 - relay			
6 - special process request			
7 - standing request for information			

Card Types and Function

Table A-2 presents the data and type sequence for inputing the TOS simulation model computer program. There are 18 card types. All of the first 17 must be present in the first simulation run of a series. After the first run of a series, it is not necessary to repeat all of the input data for subsequent runs, if the previous inputed data can be used. Card types 3, 6, 9, 11, 14, and 16 control this option of bypassing the inputing of specific types of information.

The order of data cards within a run is critical. A single card type out of sequence will, at best, yield a faulty run.

Table A-3 presents the data found on card types 1 and 2. Neither of these card types may be omitted from the input deck. Card type 1 provides 72 columns for a prose description of the mission to be simulated. This prose description called IDENT will be printed at the top of each page of program output.

Card type 2 contains the simulation parameters for this computer run. In this data card, as in all cards, where multiple columns are allocated (except for alphabetic entries), the entry must be right justified. For example, on card 2, the first entry is NSHIFT in columns 1 to 3. If only one iteration is desired, this entry must be punched in column 3. If the one is placed in column 2 with nothing in column 3, it will be interpreted as 10. Preceding blanks, on the other hand, are ignored. Table A-3 also describes the purpose of each entry.

The total of MEN(1) and MEN(2) cannot be larger than 6, within present program constraints.

The output recording options (ORD's) allow a flexibility between exact detailing of each task element processing and errors committed to general run summaries. Intermediate options, as shown in Table A-3, have a great effect on printout time, and may, therefore, be bypassed when computer processing time is limited. The run summaries are not optional, but are always printed. The run summaries include tables for manpower utilization data, message processing trimming, effectiveness data, workload summary data, and error summary data.

Table A-2

Input Card Sequence for TOS Simulation Program

Order (card type)	Description of Input Card Contents/ Function
1	Mission title
2	Simulation parameters
3	Read or skip operator parameters
4	Names of operators
5	Operator parameters (one card per operator)
6	Read or skip hour parameters
7	Names of message types
8	Hour parameters (one card for each hour)
9	Read or skip error data
10	Error data (one card for each of 3 error types)
11	Read or skip message length data
12	Message length means
13	Message length standard deviations
14	Read or skip task analysis
15	Task analysis (one card for each task element)
16	Read or skip effectiveness components
17	Effectiveness components
18	Repeat for new run or end

Table A-3

Input--Mission Identification and Simulation Parameters

Card Columns

Mission Title (card type 1)

IDENT - A run descriptor of up to 72 characters is printed on the top of each page of printout followed by the page number. 1-72

Simulation Parameters (card type 2)

NSHIFT - Number of repetitions or iterations of this mission before summary data are prepared. 1-3
IHMAX - Number of hours per shift (determines the number of type 6 cards to be read). 4-5
MEN(1) - Number of operators of type 1, number of action officers including G-3. The highest numbered A0 is the G-3. 6
MEN(2) - Number of operators of type 2, number of input output device (IOD) operators. The sum of MEN(1) + MEN(2) determines the number of type 5 cards to be read in. 7
ORO(1) - Output recording option number 1. 10
If equal 1 print input data
ORO(2) - Output recording option number 2. 11
If equal to 1 print hourly message queue
ORO(3) - Not used. . . . . . [illegible]
ORO(4) - Output recording option 4. 13
If equal to 1 print detail task element processing
ORO(5) - Output recording option 5. 14
If equal to 1 print message processing
ORO(6) - Output recording option 6. 15
If equal to 1 print hour and iteration summary
ORO(7) - Not used. 16
ORO(8) - Not used. 17
ORO(9) - Not used. 18
ORO(10) - Not used. 19
IDAY - Day of mission simulated. 20
BKLG - Number of messages in A0/G3 inbox at the beginning of the shift. 21-22
PUL - Probability of a non important undetected error in the central computer complex data store. 25-29
PUS - Prabability of a significant error in the central computer complex data store. 30-34
SRTA - System response time to an inquiry. 35-39
SRTS - Standard deviation of the system response time to an inquiry. 40-44
IATA(1,1) - Task analysis to be used for operator type 1 and message type 1. 45
IATA(1,2) - Same as above but for message type 2. 46
IATA(1,3) - Same as above but for message type 3. 47
IATA(1,4) - Same as above but for message type 4. 48
IATA(1,5) - Same as above but for message type 5. 49
IATA(1,6) - Same as above but for message type 6. 50
IATA(1,7) - Same as above but for message type 7. 51
IATA(1,8) - Same as above but for message type 8. 52
IATA(2,1) - Operator type 2, message type 1. 53
IATA(2,2) - Operator type 2, message type 2. 54
IATA(2,3) - Operator type 2, message type 3. 55
IATA(2,4) - Operator type 2, message type 4. 56
IATA(2,5) - Operator type 2, message type 5. 57
IATA(2,6) - Operator type 2, message type 6. 58
IATA(2,7) - Operator type 2, message type 7. 59
IATA(2,8) - Operator type 2, message type 8. 60
NTE - Number of task elements over all task analyses to be used (determines the number of type 15 cards to be read in. 61-63
Y - Random number to be used to initialize random number generator. An eight digit positive odd octal number must be used. 65-70

Table A-4

Input--Operator Parameters

		Card Columns
Read or skip operator parameters (card type 3)		
NSKIP -	If equal to 1 skip to reading card type 6. If not equal to 1 read card types 4 and 5....................	1
Names of operators (card type 4). Reads in one four character name for each of the men specified in card type 2.		
NAME(1) -	Name of operator number one......................	1-4
NAME(2) -	Name of operator two..............................	5-8
NAME(M) -	Name of operator M	
Operator parameters (card type 5). One card is read in for each man specified in card type 2.		
M -	Man number...	1
F(M) -	The speed factor of this man. An average man is 1.0, a faster than average man has an F(M) value less than 1.0. A slower than average man has an F(M) value greater than 1.0..................................	5-9
PREC(M) -	The precision factor of this man. An average man who makes an average number of errors would have a precision factor of 1.0. A highly precise man who makes many fewer than average errors would have a precision factor of 0.9. Perfection is represented by a value of 0.8 and complete failure which would result in unending runs is represented by a value of 1.2................	10-14
STRM(M) -	The stress threshold of this man. The number of priority messages in the backlog for this man which will produce a maximum effort......................	15-19
ASP(M) -	The level of aspiration of this man. An aspiration of 1.0 represents striving for perfection................	20-24

Table A-5

Input--Hour Parameters

	Card Columns
Read or skip hour parameters (card type 6)	
ISKH If equal to 1 skip to card type 9. If not equal to 1, read card types 7 and 8.	1
Names of message types (card type 7)	
NMTYP(1) - Name of message type 1	1-4
NMTYP(2) - Name of message type 2	5-8
NMTYP(3) - Name of message type 3	9-12
NMTYP(4) - Name of message type 4	13-16
NMTYP(5) - Name of message type 5	17-20
NMTYP(6) - Name of message type 6	21-24
NMTYP(7) - Name of message type 7	25-28
Hour parameters (card type 8) One card for each hour specified in card type 2 by IHMAX.	
IH - Hour number	1-2
IGP(IH) - Number of messages arriving in AO/G3's inbox in the last 15 minutes of this hour	3-4
IGR(IH) - Number of messages arriving in AO/G3's inbox randomly throughout this hour	5-6
IUR(IH) - Non functional	7-8
FRET(1,IH) - Cumulative proportional occurrence of message type 1 - add	10-14
FRET(2,IH) - Type 2 - change	15-19
FRET(3,IH) - Type 3 - delete	20-24
FRET(4,IH) - Type 4 - query	25-29
FRET(5,IH) - Type 5 - relay	30-34
FRET(6,IH) - Type 6 - SPR	35-39
FRET(7,IH) - Type 7 - SRI	40-44
FREP(1,IH) - Cumulative proportion of message occurrence of priority type 1 - routine	45-49
FREP(2,IH) - Priority type 2 - priority	50-54
FREP(3,IH) - Priority type 3 - operational immediate	55-59
FREP(4,IH) - Priority type 4 - flash	60-64
FREP(5,IH) - Priority type 5 - presidential interrupt	65-69
FRER(IH) - Frequency of routine message arrival per hour	70-74
FREO(IH) - Frequency of arrival of other than routine messages per hour	75-79

Table A-6

Input--Error Data

	Card Columns
Read or skip error data (card type 9)	
ISKIP - If equal to 1 skip to card type 11, If not equal to 1, read card type 10.	1
[illegible] (card type 10)	
IE - Type of error. 1=commission, 2=abbreviation, typographical or spacing, and 3=omission.	1
ER(IE,1) - Error rate per 100 characters of message type 1	2-9
ER(IE,2) - Message type 2	10-17
ER(IE,3) - Message type 3	18-25
ER(IE,4) - Message type 4	26-33
ER(IE,5) - Message type 5	34-41
ER(IE,6) - Message type 6	42-49
ER(IE,7) - Message type 7	50-57
ER(IE,8) - Non functional	58-65
ERPG - Percentage of G3/AC errors which produce error routines	66-72
ERPI - Percentage of VIOD errors which produce error routines	73-79

Table A-7

Input--Message Length Data

	Card Columns
Read or skip message length data (card type 11)	
ISKIP - If equal to 1, skip to card type 14 If not equal to 1, read card types 12 and 13	1
Read message length means (card type 12)	
INC(1) - Number of characters in transformed message type 1	1-9
INC(2) - Message type 2	10-19
INC(3) - Message type 3	20-29
INC(4) - Message type 4	30-39
INC(5) - Message type 5	40-49
INC(6) - Message type 6	50-59
INC(7) - Message type 7	60-69
INC(8) - Non functional	70-79
Read message length standard deviations (card type 13)	
INS(1) - Standard deviation of characters in transformed message type 1	1-9
INS(2) - Message type 2	10-19
INS(3) - Message type 3	20-29
INS(4) - Message type 4	30-39
INS(5) - Message type 5	40-49
INS(6) - Message type 6	50-59
INS(7) - Message type 7	60-69
INS(8) - Non functional	70-79

The variable IDAY determines the day number of a simulation with reference to the number of continuous days worked at this task and is used witnin the model to trigger fatigue effects.

The variable matrix IATA determines which task analysis (i. e., procedure) will be used in the processing of a message. It is presently limited to a maximum of four task analyses. None of these may have more than 20 task elements.

Table A-4 shows the card formats for card types 3, 4, and 5. Card type 3 determines whether or not new operator description data will be read in. Card type 4 specifies the four character names of the known operators (i. e., UIOD, etc.). One card type 5 is required to describe each of the operators called for on card type 2. Since the man number is on each card, ordering of these cards is not required.

Table A-5 describes the data for card types 6, 7, and 8. Card type 6 determines whether or not new hour parameters will be read. Card type 7 provides for the readin of names for each of seven message types. Each name consists of four characters. This name will be printed out in the detailed message processing if this option is called. For every hour to be simulated, one card of type 8 must appear. The hour parameters include message workload, message type frequency, message priority distribution, and message frequency of arrival. The type 8 cards need not be ordered since the hour is specified on each card.

Table A-6 shows the card formats for card types 9 and 10. Card type 9 determines whether or not error data (i.e., card type 10) is read in or not. Card type 10 contains the error rate data for each message type by each error type. Error originator probabilities are also shown. Card types 10 do not have to be in order of error since error type is specified on each card.

Table A-7 shows the format for card types 11, 12, and 13. Card type 11 determines whether or not message length data (i. e., card types 12 and 13) will be read in or not. Card type 12 contains the mean message length data for each message type. Card type 13 contains the message length standard deviation data for each message type.

Table A-8 shows the card formats for card types 14 and 15. Card type 14 determines whether or not task analytic data (i. e., card type 15) will be read in or not. One card type 15 must be input for each task element in the task analysis, as specified by NTE in card type 2. The card type 15 contains all timing and sequencing data required to simulate a task element.

Table A-9 shows the card formats and contents of card types 16, 17, and 18. Card type 16 determines whether or not new effectiveness component data (i. e., card type 17) will be read in or not. Card type 17 contains the correlations among effectiveness components, as well as the relative weight of each component in the computation of overall effectiveness (see Appendix C).

Card type 18 determines whether or not a new run should be set up. It thereby determines whether or not a card type 1 will be read, thus cycling through cards 1-17 again.

Table A-8

Input--Task Analytic Data

		Card Columns
Read or skip task analysis (card type 14)		
ISKIP -	If equal to 1, skip to card type 16.................... If not equal to 1, read card type 15.	1
Task analysis (card type 15) One card for each task element specified by NTE in card type 2.		
K -	Task analysis number..............................	1-2
I -	Task element number within this task analysis.........	3-5
JTYPE(I, K) -	Task element type where 1 = a task element on which the message may be rejected with a probability specified by AVPROB(I, K). 2 = a task element in which the number of characters for this message type will be multiplied times the stoachistically determined mean time to produce the time required to transform the message. 3 = a decision task element where operator factors such as speed [F(M)], precision [PREC(M)], and stress level [STR(M)], are not allowed to affect the duration or success probability of the task element. 4 = an equipment task element where operator factors are not considered and the task cannot be failed. 5 = not used, 6 = a special type of branch task element where either a "COR" or "ERR" response is expected........	7
CRIT(I, K) -	Criticality of the task element. C = critical, not C is not critical......................................	8
END(I, K) -	Message processing segment ended by this task element, if any..	10
IJF(I, K) -	The number of the task element which will follow this one if this task element is a failure..................	12-14
IJS(I, K)-	The number of the task element which will follow this on on if this task element is a success..................	15-17
AVGTM(I, K) -	Task element mean performance time................	20-29
SIGMA(I, K) -	Standard deviation of AVGTM(I, K)..................	30-39
AVPROB(I, K) -	Task element success probability, the probability that the following task will be IJS(I, K) and not IJF. Also the probability of message rejection when JTYPE(I, K) = 1..	40-49
UETYPE(I, K) -	Undetected error type T = transform, not T = all others..	50
UEP(I, K) -	Undetected error probability.........................	51-56

Table A-9

Input--Effectiveness Component Data

		Card Columns
Read or skip effectiveness components (card type 16)		
ISKIP -	If equal to 1 skip to read card type 18. If not equal to 1 read card type 17	1
Effectiveness components (card type 17)		
CC12 -	Correlation between thoroughness and completeness	1-4
CC13 -	Correlation between thoroughness and responsiveness	5-9
CC14 -	Correlation between thoroughness and accuracy	10-14
CC23 -	Correlation between completeness and responsiveness	15-19
CC24 -	Correlation between completeness and accuracy	20-24
CC34 -	Correlation between responsiveness and accuracy	25-29
W(1) -	Relative weight of thoroughness in computing overall effectiveness	30-34
W(2) -	Weight of completeness	35-39
W(3) -	Weight of responsiveness	40-44
W(4) -	Weight of accuracy	45-49

The weights must sum to 1.0.

Repeat for new run (card type 18)		
IREP -	If equal to 1, read card type 1. If not equal to 1 terminate program	1

Glossary

Table A-10 presents a glossary of FORTRAN variable names. This glossary includes all variables mentioned in this report, except for those already defined in Tables A-1 through A-9. Table A-10 is partitioned into dimensional variables (i. e., variables which are actually a matrix of related variables) and nondimensional variables.

Table A-10

Glossary of Principal FORTRAN Variable Names

Dimensional Variables

Z(M)	Current time last worked
TW(IH, M)	Total hours worked in a shift
NOSUC(M)	Number of successes for man M
NOFAIL(M)	Number of failures for man M
EC(NEC)	Value of effectiveness component
PERF(M)	Performance of man M
AVAIL(M)	Availability indicator for man M; 1=available;0=not available
IDI(IH, M)	Idle time for man M
INFOLS(CMSG)	Information loss for this message
PASP(M)	Permanent aspiration level (necessary because aspiration level may change within a given iteration)
INTRPT(M)	Set to 1 if this man has an interrupted message
MSGIRP(M)	Message number of interrupted message, this man
MESS(LA, J)	Messages: LA=1 total for hour; LA=2 to do this hour, in queue
STR(M)	Operator stress
OUT(MSG, J)	Outcome for this message C = Complete I = Interrupted R = Rejected Blank = Ready for processing if it has arrived

Table A-10 (Cont.)

Nondimensioned Variables

MSGNO	Number of message being processed
NOMSGS	Number of messages arrived with priority greater than 1
IHMAX	Length of workday (hours)
MSG	Number of next message to be processed
ST	Start time for message processing
RY	Pseudo random number equiprobable in 0-1 internal
RD	Pseudo random (random deviate), mean=0, sigma=1
NSFT	Current iteration number
NSHIFT	Number of iterations to be performed
SF	Stress factor
TIME	Execution time of a task element
ZIF	Stress function for execution time
V	Basic execution time function
ZIH	IH minus 1 in seconds
TNUE	Total number of undetected errors in a message
SIF	Success or failure indicator
EFF	Efficiency
PAFA	Pace Adjustment Factor due to aspiration
PAFW	Pace Adjustment Factor due to work fatigue
PROB	Temporary for task element probability, adjusted
CMSG	Cumulative message number
KINKS	Number of messages interrupted from previous hour

Time Segments

SEGS(CMSG, 1)	TARIV(MSG, 1) = time arrive in AO/G-3 queue
(CMSG, 2)	Z(M) at PROC start = time of message start
(CMSG, 3)	Z(M) at PROC task element triggered = select format
(CMSG, 4)	TARIV(MSG, 2) = time arrive IOD queue
(CMSG, 5)	Z(M) t-e triggered = IOD request format
(CMSG, 6)	Z(M) t-e triggered = IOD send message
(CMSG, 7)	Z(M) end of PROC triggered = IOD finished with message

Subroutines

Table A-11 presents the names and functions of each subroutine of the computer simulation program. The first routine - SIPS - is actually the main routine which then calls the subroutines as appropriate. This fragmentation of the program into many subroutines allows the program to be modified more easily.

Table A-11

Subroutine Names and Functions

Routine	Mnemonic	Function
SIPS	Simulation of Information Processing Systems	Main control program
SIMPAM	Simulation Parameters	Read simulation parameters
PEOPLE	-	Read/generate personnel characteristics
HOUR	-	Read input given by hour
ERROR	-	Read error rate data
RESET	-	Prepare conditions for start of new shift
BAKLOG	backlog	Determine G-3 message queue characteristics
MESGEN	message generator	Generate message queues
MANDET	man determination	Selects a man and a message to simulate next
RESHR	reset for hour	Prepare conditions for new hour
ITSUM	iteration summary	Print results of simulating each iteration of a shift
RUN SUM	run summary	Print summary of ITER iterations of a shift
PROC	processing	Simulation for a message
RAND	random numbers	Generate pseudo random no. 0-1
INPOA	inverse normal probability	Generate pseudo random no. normal destribution
FATIGU	fatigue	Calculate work fatigue
ASPIRE	aspiration	Calculate aspiration
POIS	POISSON	Random number from poisson distribution

APPENDIX B

Logic Flow Diagrams for the TOS Simulation Model

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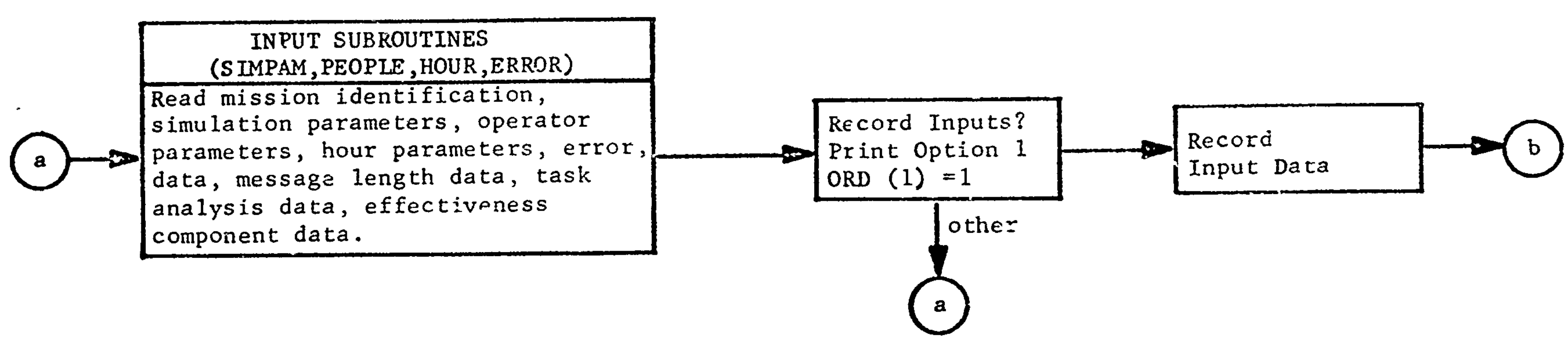
FIGURE B-1

MAIN SEQUENCE LOGIC FLOW FOR TOS MODEL

(ROUTINE SIPS)



b

```
SUBROUTINE RESET
Reset conditions required to start
a new shift (i.e. a new simulation
iteration or run):
     CMSG = 0 : message number
       IH = 1 : first hour
The following for MAN = 1,.... MEN(3) (All Men)
     Z(M) = 0:last time simulated
 TW(IH,M) = 0:total time worked (simulated) per hour
IOL(IH,M) = 0:total time idled per hour
ASP (M)   = PASP(M)
PERF(M)   = ASP(M): initialize performance

  NOSUC(M)=0: count of successes
 NOFAIL(M)=0: count of noted failures

Reset all message queues.
Preliminary calculations required for effectiveness.
Reset all counters except run summary counters.
```

```
ENTER MESSAGE GENERATION SUBROUTINE
        FOR G-3  (BAKLOG)
Generate message backlog for G-3, for those
messages in the G-3 backlog queue.
  Input to subroutine: BKLG
  Output from subroutine for each message:
      CMSG   Cumulative Message No.
      PRIOR (MSG,J)   Priority Code
      TYPE  (MSG,J)   Type of Message
      LENTH (MSG,J)   No. of Characters
      TARIV (MSG,J)   Time of Arrival
```

c

Figure B-1 (cont.)

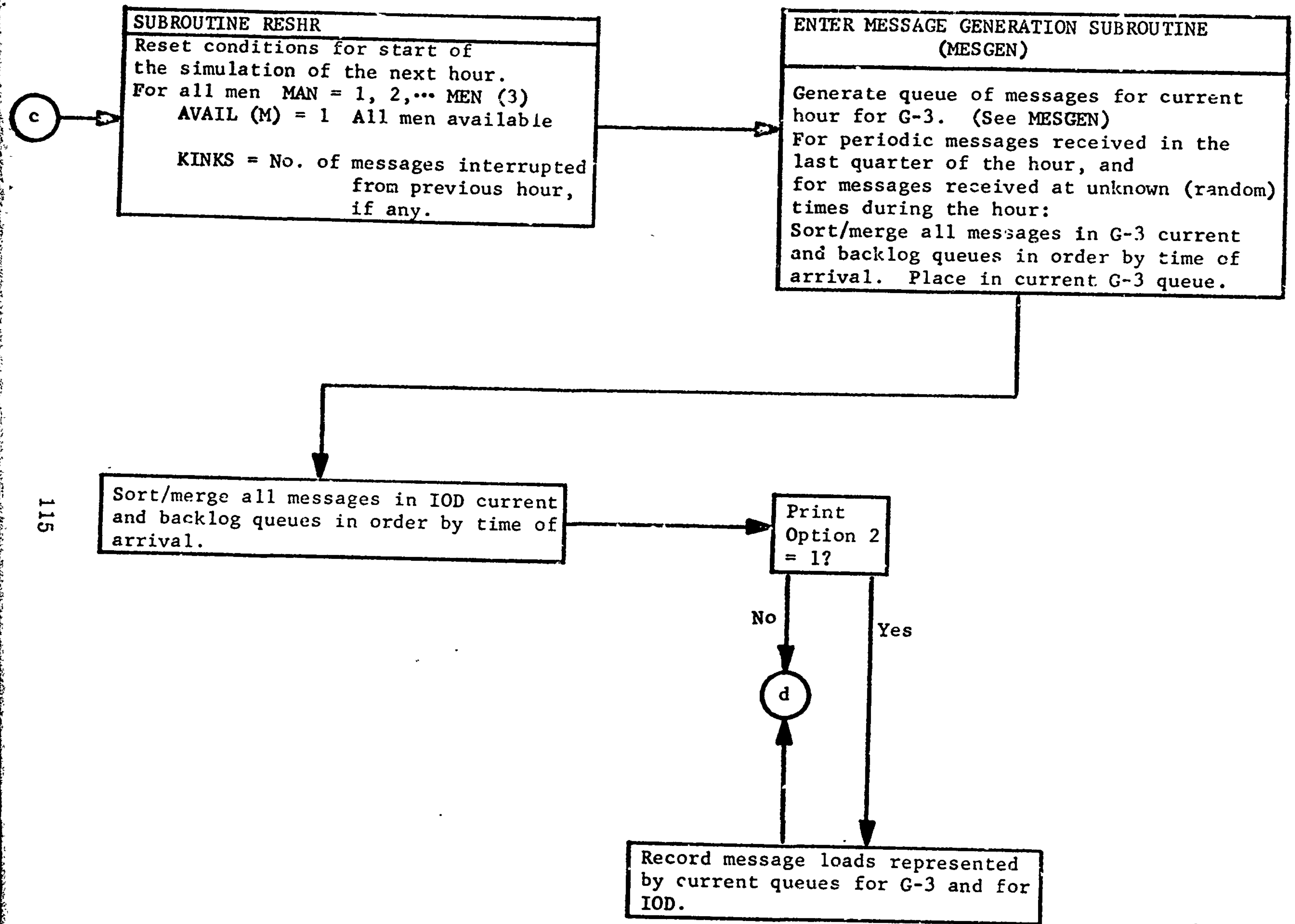


Figure B-1 (cont.)

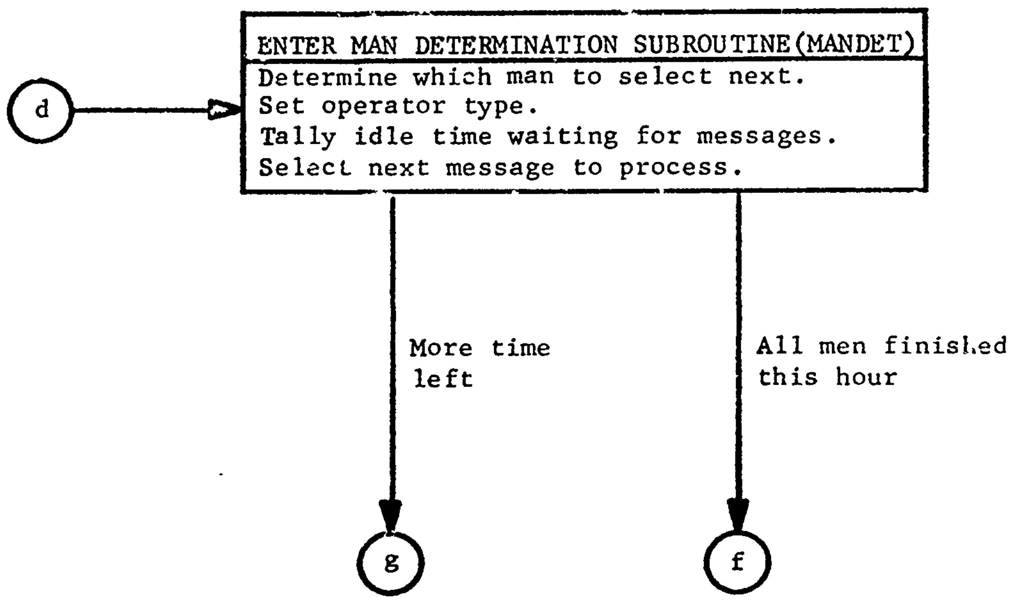


Figure B-1 (cont.)

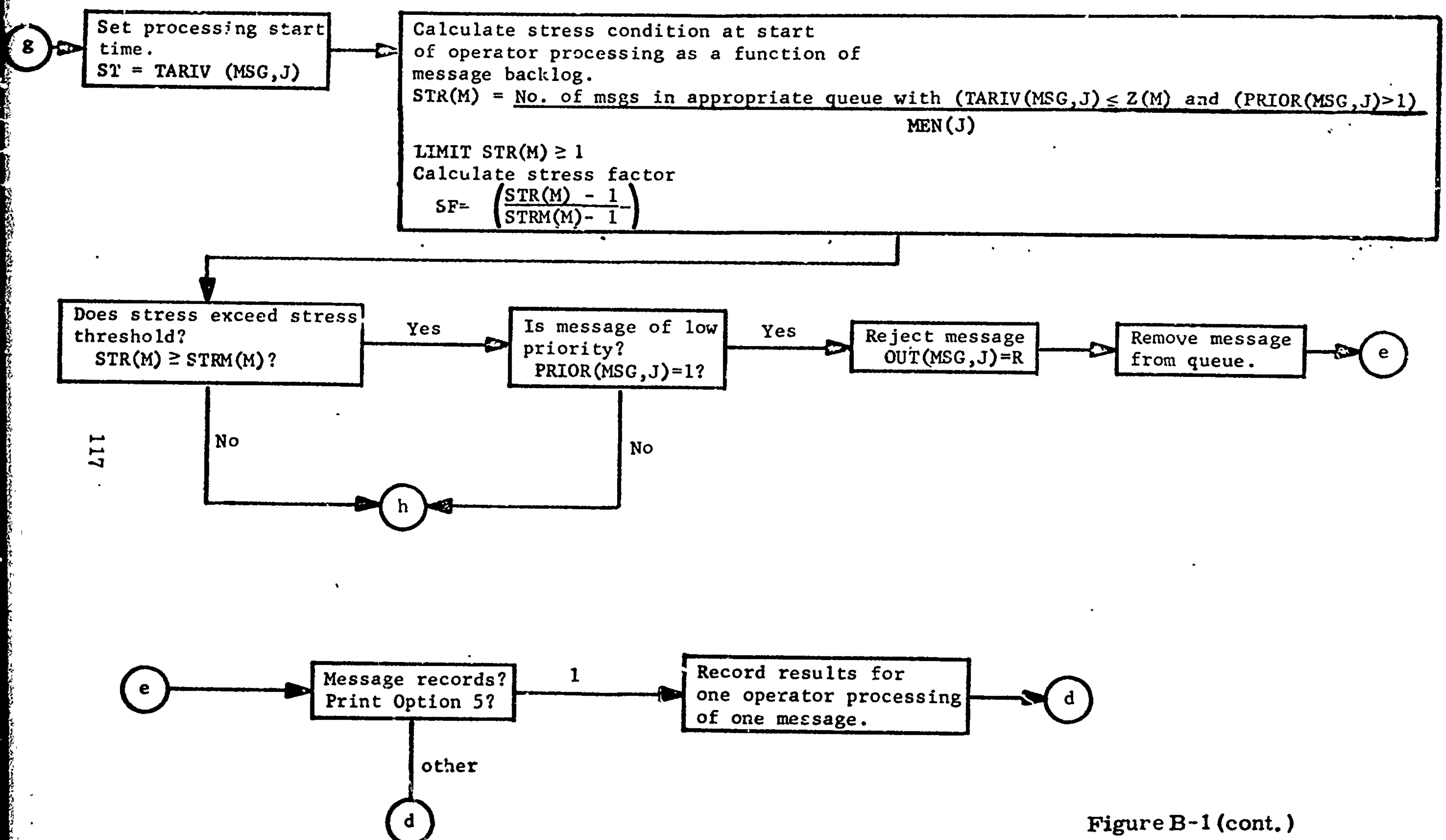


Figure B-1 (cont.)

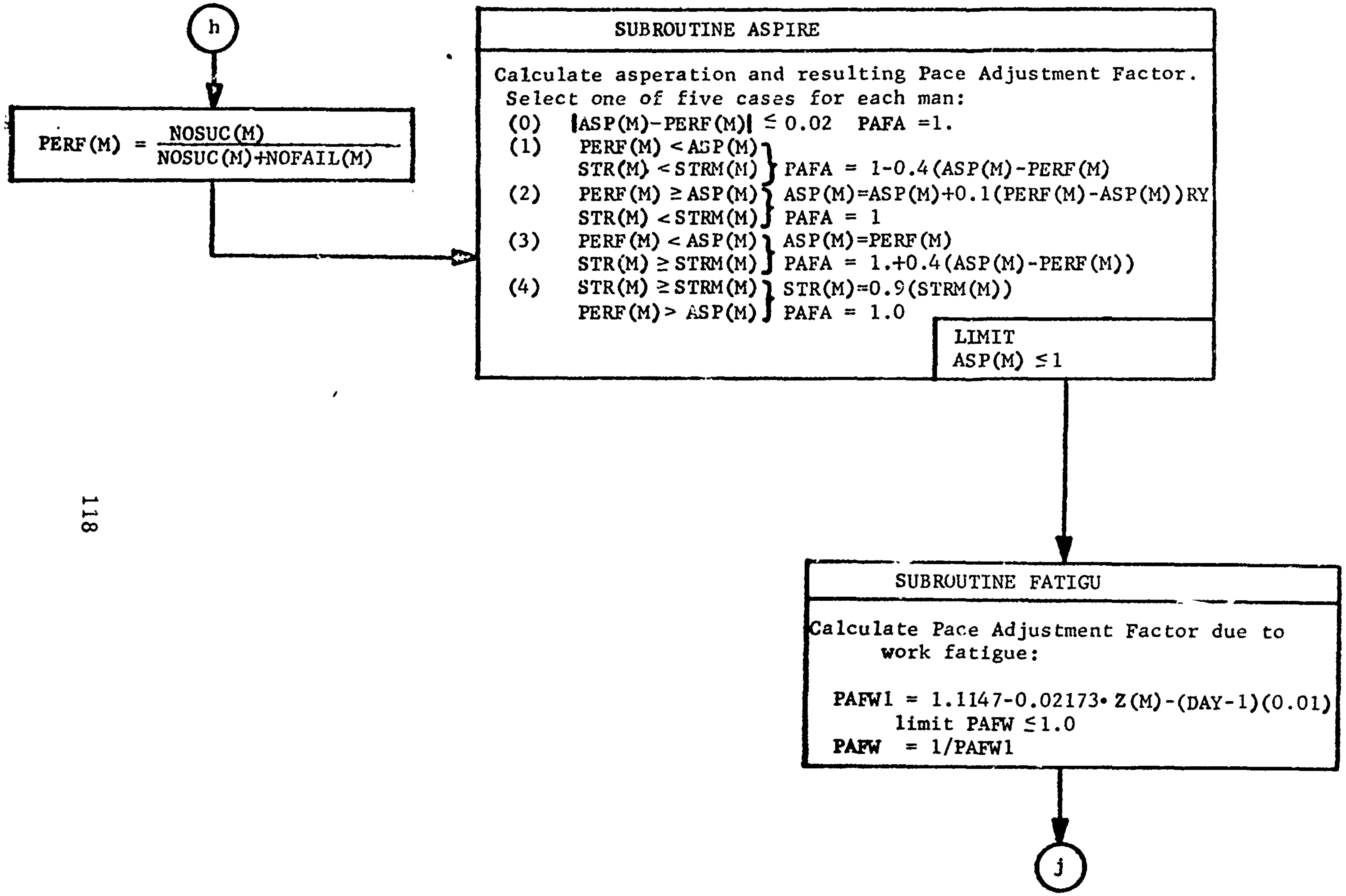


Figure B-1 (cont.)

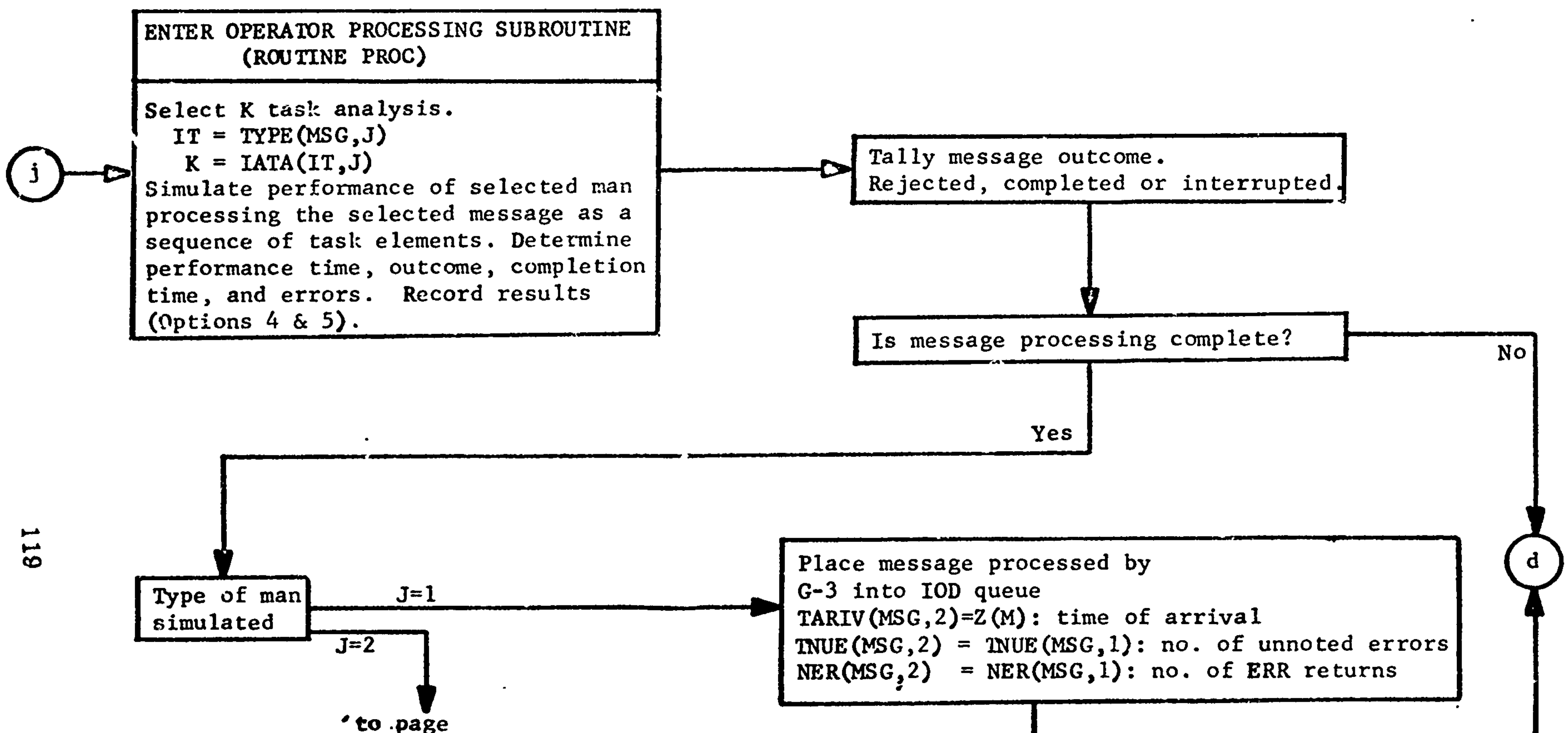


Figure B-1 (cont.)

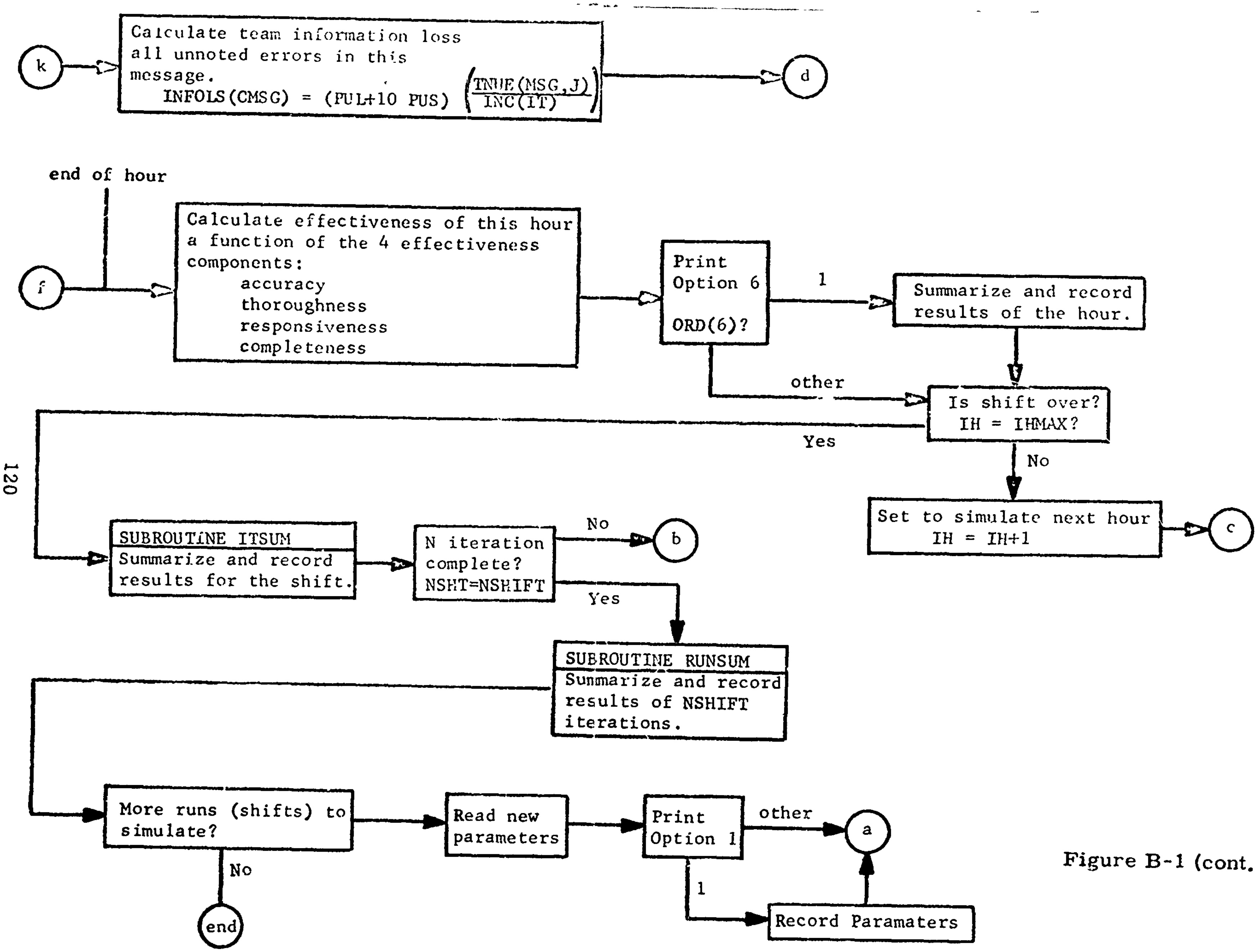
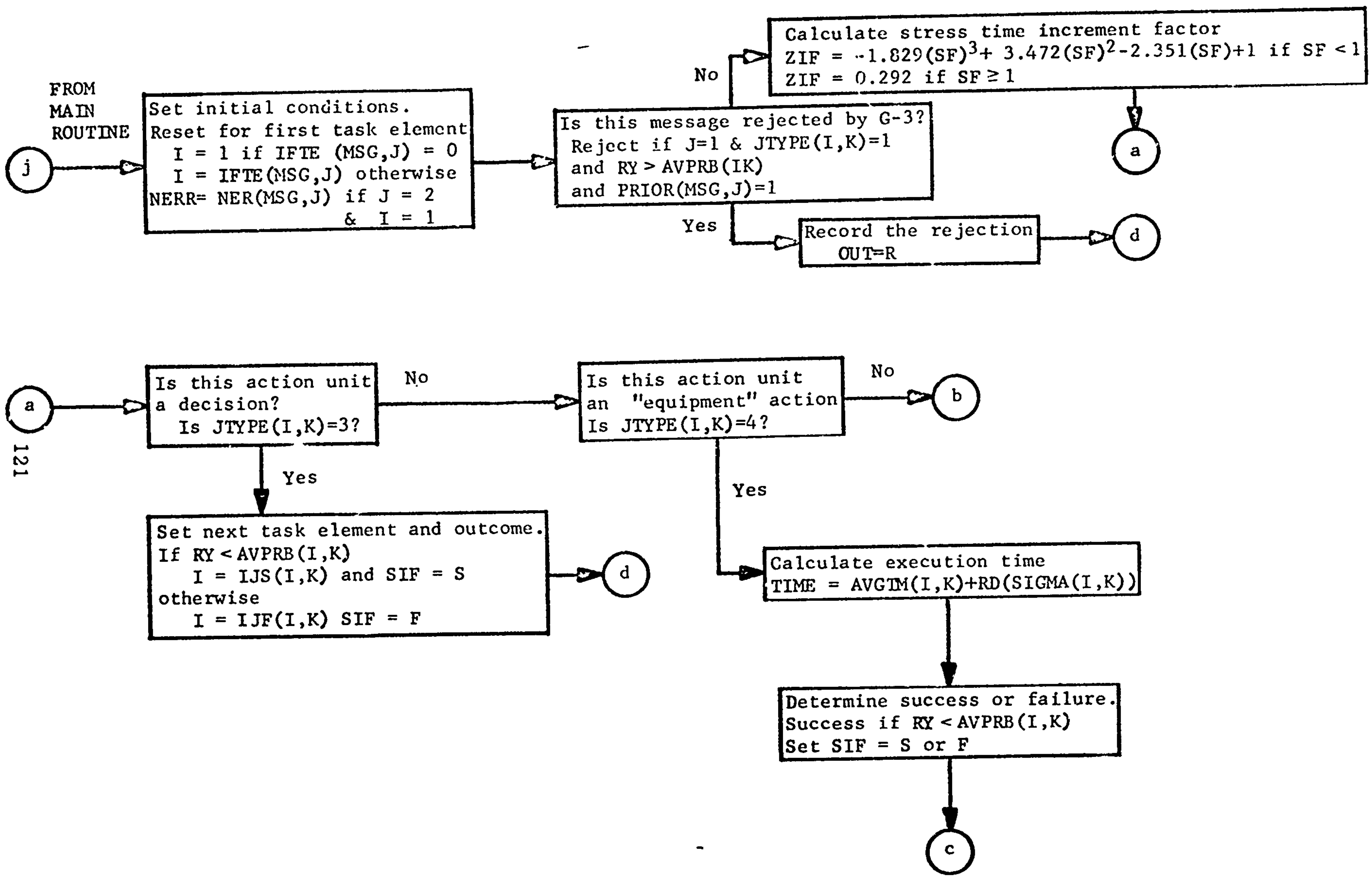


Figure B-1 (cont.)

FIGURE B-2

OPERATOR PROCESSING SUBROUTINE (ROUTINE PROC)



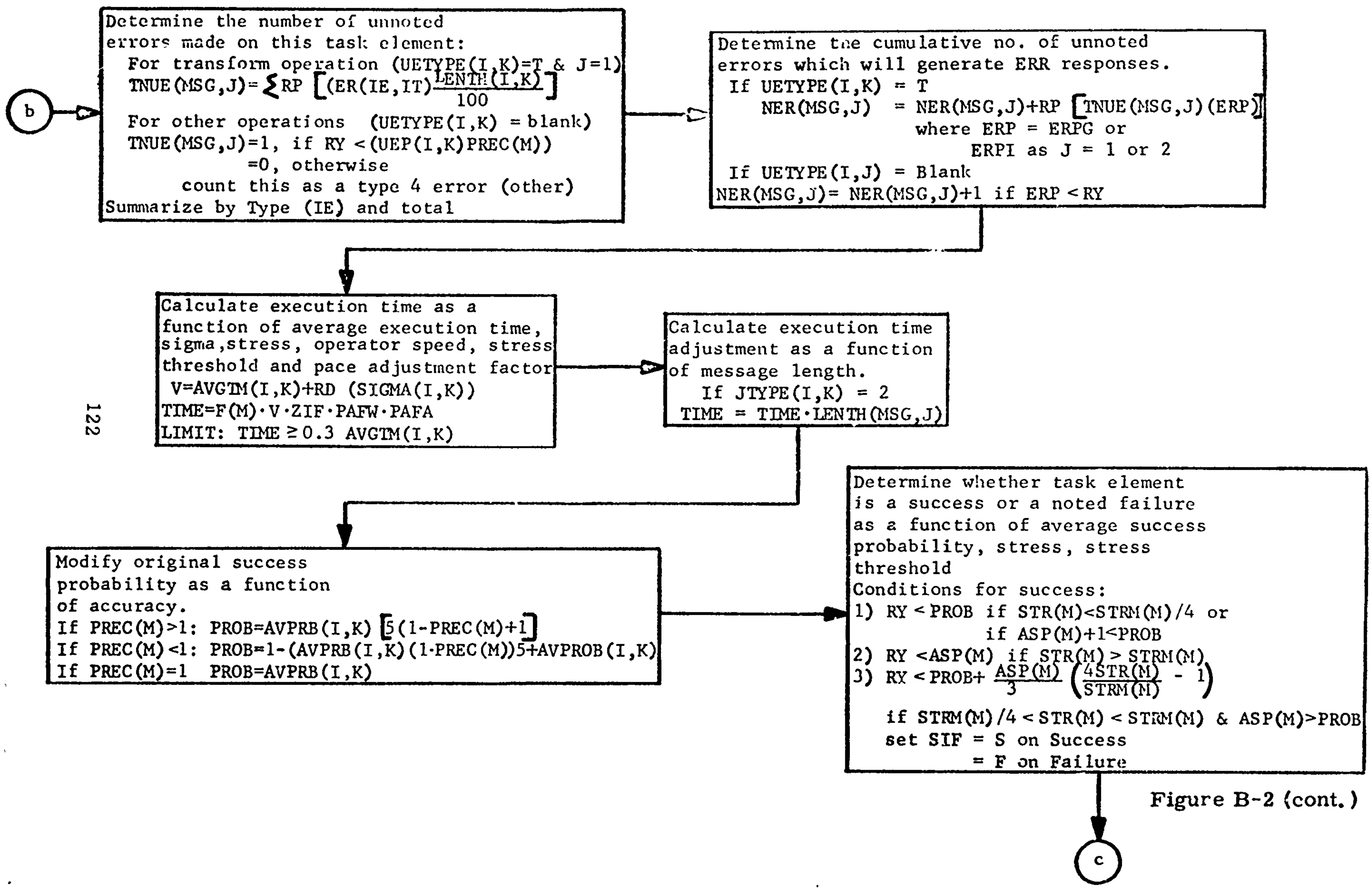


Figure B-2 (cont.)

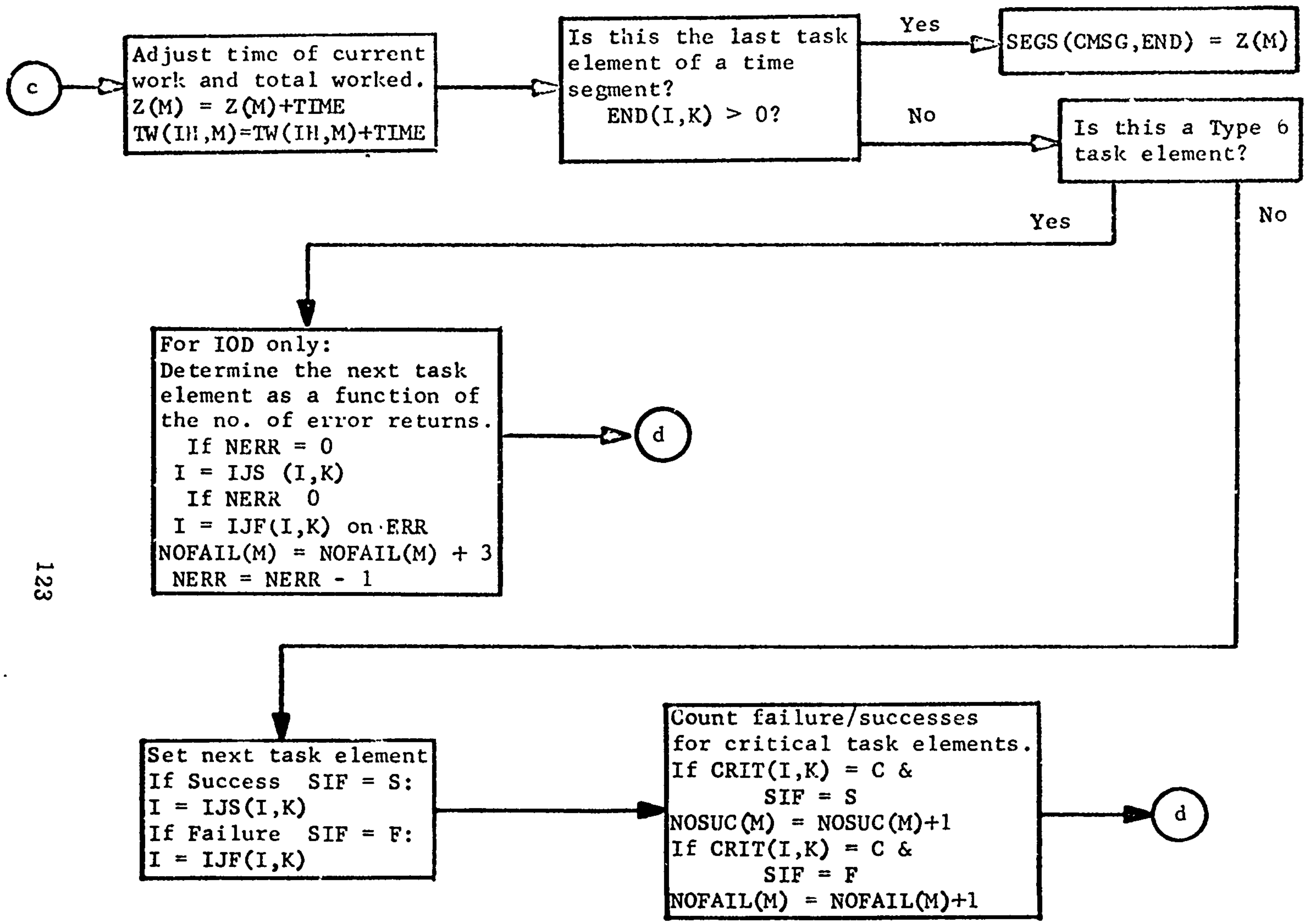


Figure B-2 (cont.)

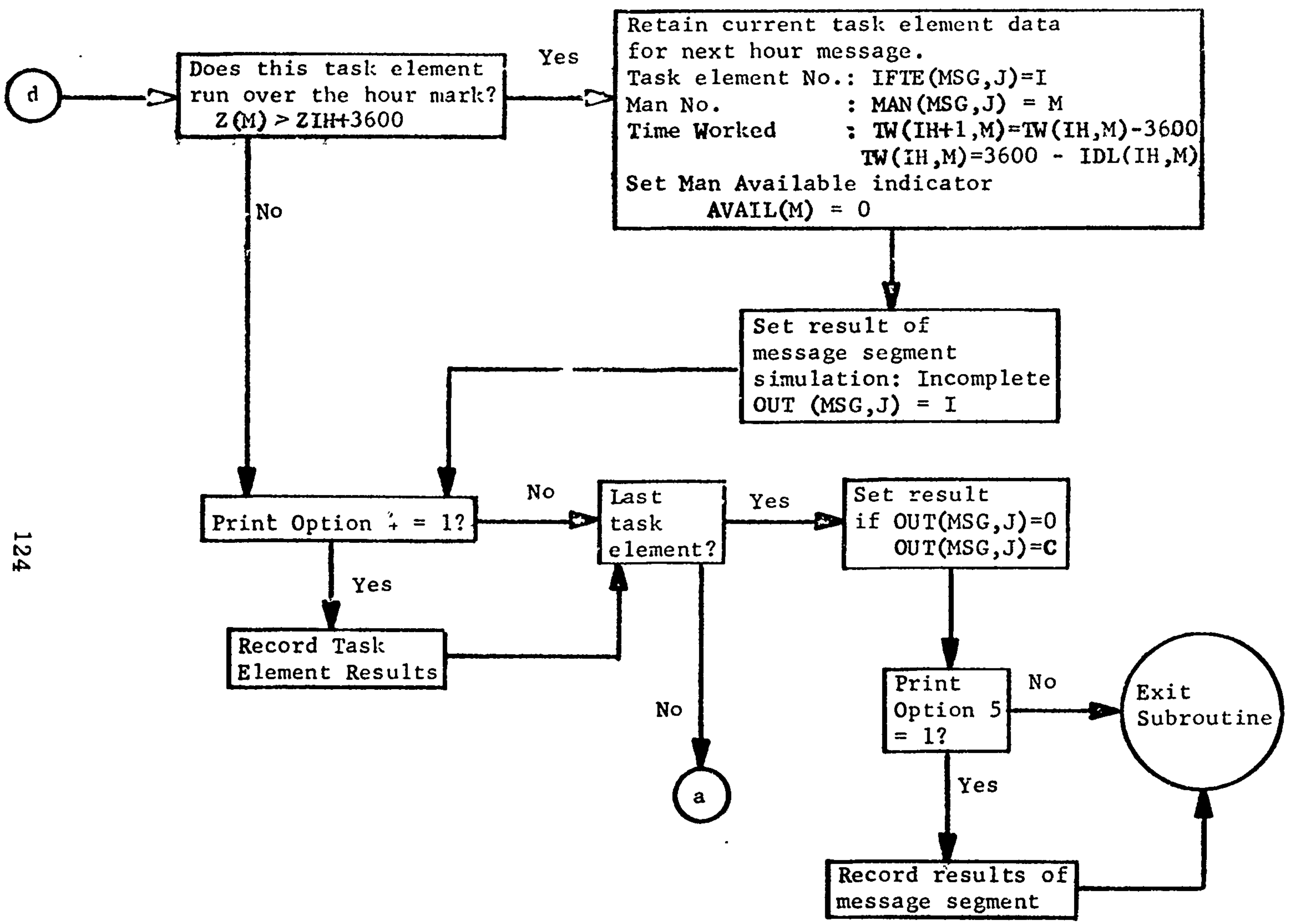
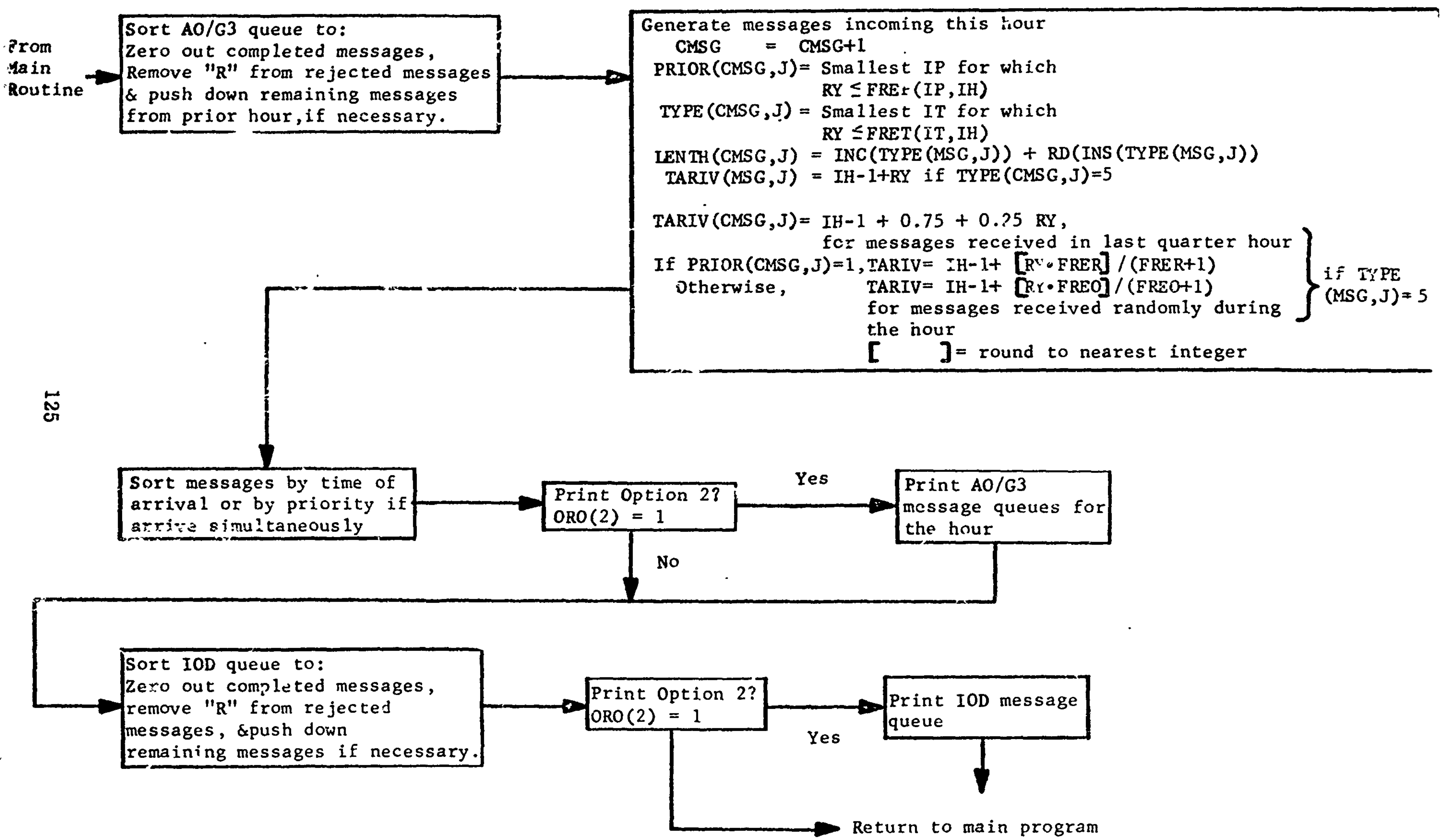


Figure B-2 (cont.)

FIGURE B-3

MESSAGE GENERATION SUBROUTINE (MESGEN)



MAN DETERMINATION SUBROUTINE (MANDET)

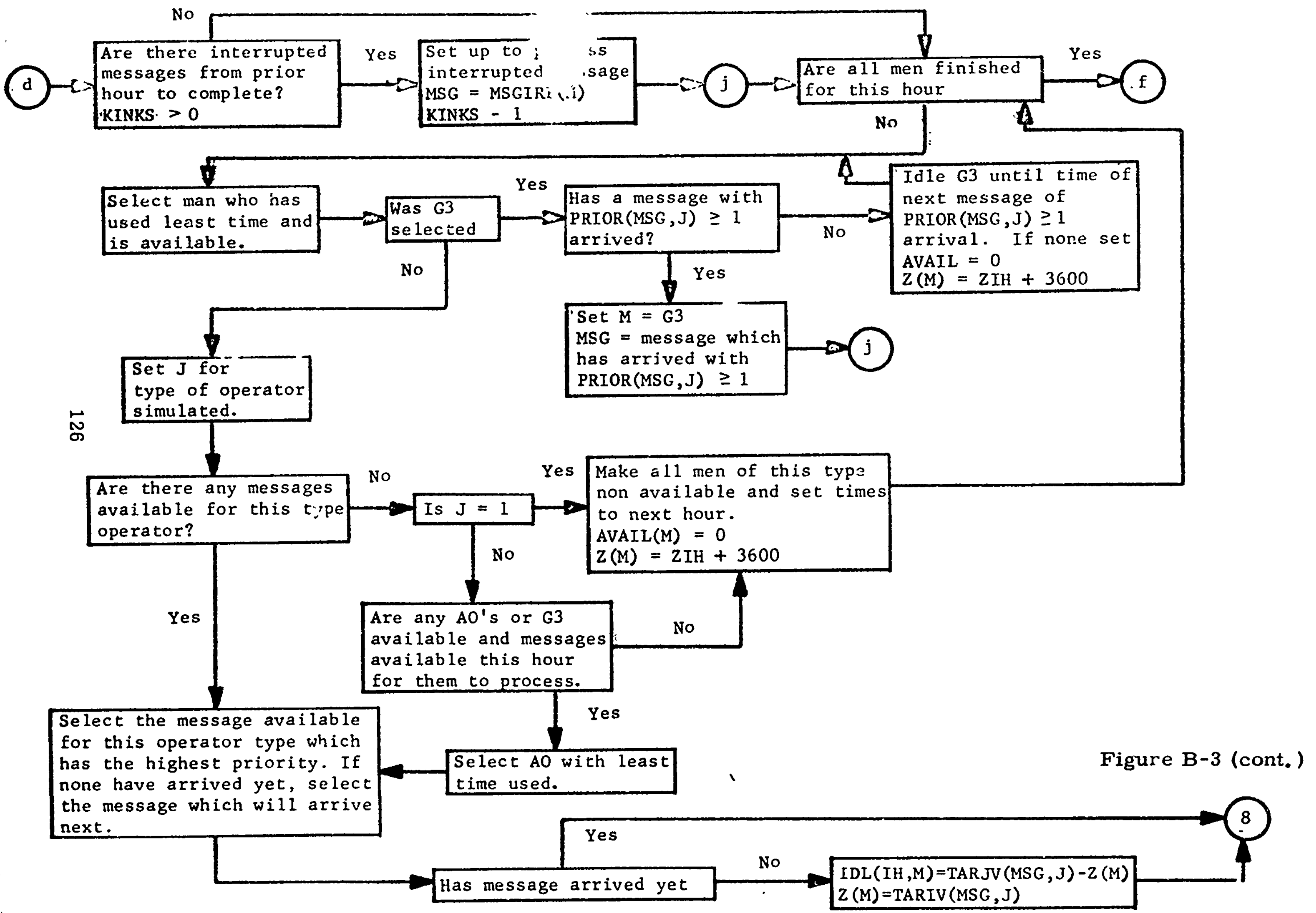


Figure B-3 (cont.)

APPENDIX C

Logic for Efficiency Calculation

Criteria for Synthetic Measure

A synthetic, overall measure of effectiveness, E, should have the following properties for all E from 1 to n, where $E = f(e_1, e_2, \ldots, e_n)$

1. If the components e_i each in the range 0 to 1 are highly correlated, then the function should become additive. In this case one component alone might suffice.

2. Penalizes high variability of components if the components are uncorrelated (or independent)

3. Correct behavior in the limit:

   (a) $E = 0$ when $e_i = 0$
   (b) $E = 1$ when $e_i = 1$
   (c) $E = c$ when $e_i = c$

   Condition (c) is desirable although not essential.

4. Correct directionality:

   $$\frac{\partial f}{\partial e_i} > 0$$

   as any component is changed, E will also change in the same direction.

5. Continuity--$\lim f(e_1, e_2, \ldots, e_i, \ldots e_n) = f(e_1, e_2, \ldots, c, \ldots e_n)$ with respect to components $e_i \to c$---as the component values are changed continuously, E changes continuously (no jumps or gaps in the values of E). Also higher derivative should be continuous.

6. Continuity with respect to the correlation among components--as the correlation among components changes continuously, E changes continuously.

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Suggested Formula and its Characteristics

The following formula satisfies all the above properties:

$$E = \frac{1}{{}_nC_2}\left(r_{12}^2 + r_{13}^2 + \ldots + r_{n-1,n}^2\right)\sum_{i=1}^{n} w_i e_i$$

$$+ \frac{1}{{}_nC_2}\left[{}_nC_2 - \left(r_n^2 + r_n^2 + \ldots + r_{n-1,n}^2\right)\right]\prod_{i=1}^{n} e_i^{m_i}$$

with $\Sigma w_i = 1$ and $\Sigma m_i = 1$, and r_{ij} the correlation between e_i and e_j. It is of the form $E = a\Sigma w_i e_i + b\pi e_i^{m_i}$.

If all r_{ij} are zero, the first term is zero since $a = 0$, and the second term is $\prod_{i=1}^{n} e_i^{m_i}$ since $b = 1$. The w_i and $\frac{1}{m_i}$ are weights for the components. Thus, $E = \pi e_i^{m_i}$. If all r_{ij} are ± 1, the first term is $\sum_{i=1}^{n} w_i e_i$ (since $a = 1$) and the second term is zero (since $b = 0$). Thus, $E = \Sigma w_i e_i$ and criterion 1 is satisfied. Note that there are ${}_nC_2$ different correlation coefficients, where ${}_nC_2$ is the number of combinations of n things taken two at a time, also written $\binom{n}{2}$.

It is seen that when all $r_{ij} = 0$, the formula is multiplicative. It is well known that the largest product for a given sum of the e_i values results when the e_i values are equal. This is illustrated by the fact that a cube has the largest volume for any rectangle parallepiped. If any component e_i is zero, the product is zero. Thus, criterion 2 is satisfied.

If $e_i = 0$ for all i, then both $\Sigma w_i e_i$ and $\pi e_i^{m_i}$ are zero and $E = 0$.

If $e_i = 1$ for all i, then we have

$$E = \frac{1}{{}_nC_2} R\Sigma w_i + \frac{1}{{}_nC_2} [{}_nC_2 - R] \text{ where}$$

$$R = r_{12}^2 + r_{13}^2 + \ldots + r_{n-1,n}^2$$

$$E = \frac{1}{{}_nC_2} R + \frac{{}_nC_2}{{}_nC_2} - \frac{R}{{}_nC_2} = 1 \text{ since } \Sigma w_i = 1$$

If $e_i = c$ where $0 < c < 1$,

$$E = \frac{1}{{}_nC_2} R \sum_{i=1}^{n} w_i C + \frac{1}{{}_nC_2} [{}_nC_2 - R] \prod_{i=1}^{n} C^{m_i}$$

$$= \frac{1}{{}_nC_2} RC\sum_{i=1}^{n} w_i + \frac{1}{{}_nC_2} [{}_nC_2 - R] C^{\Sigma m_i}$$

$$= \frac{RC}{{}_nC_2} + [1 - \frac{R}{{}_nC_2}] C \quad \text{since } \Sigma m_i = 1$$

$$= \frac{RC}{{}_nC_2} + C - \frac{CR}{{}_nC_2} = C$$

Therefore criterion 3 (a), (b), (c) are satisfied.

It can also be seen from the formula that as any e_i increases, E increases. Accordingly, criterion 4 is satisfied.

Also, the two terms are continuous with respect to each e_i variable, satisfying criterion 5.

Criterion 6 is satisfied since the r_{ij} values are squared and power functions are continuous. Therefore, E is continuous with respect to the r_{ij} values.

The form of R is somewhat arbitrary. As the absolute magnitude of any r_{ij} increases, R also increases. It is not claimed that R is a standard statistic. However, for various intermediate r_{ij} values, the overall formula behaves in the expected manner. Since the correlation coefficients can be positive or negative, R cannot be of the form Σr_{ij} because the sum might be zero, while some of the variables are highly correlated. However, either $\Sigma |r_{ij}|$ or Σr_{ij}^2 will behave in the desired manner. The latter will weight the multiplicative term more heavily (when $R \neq 1$). The product of the correlation coefficients was also ruled out since, in this case, R will be zero if only one r_{ij} is zero.

Reasonableness of Output

In order to test the reasonableness of the formula, a set of 15 hypothetical cases was derived. Each case consisted of four components (e_i values). These values are listed in Table 1. The product moment correlation coefficients were calculated to be:

$$r_{12} = .0179,\ r_{13} = -.1897,\ r_{14} = -.2411,\ r_{23} = -.3734,$$
$$r_{24} = -.0601, \text{ and } r_{34} = -.4689.$$

$R = \Sigma r_{ij}^2 = .45734$ and ${}_4C_2 = 6$. $E = \frac{1}{24} R \sum_{i=1}^{4} e_i + \frac{1}{6}(6 - R)(\prod_{i=1}^{e} e_i)^{\frac{1}{4}} =$

$.019055(e_1 + e_2 + e_3 + e_4) + .9237 \sqrt[4]{e_1 e_2 e_3 e_4}$ assuming $w_i = m_i = \frac{1}{4}$.

Table 1 gives the resultant values of E and the respective rank for each case.

Table 1

Test Case Data

Case	e_i	e_2	e_3	e_4	E	E Rank
1	.5	.6	.4	.8	.5608	3
2	.2	.9	.8	.4	.5090	7
3	.9	.95	.5	.2	.5625	4
4	.7	.6	.6	.65	.6365	2
5	1	0	1	0	.1126	14.5
6	.7	.7	.7	.7	.7000	1
7	.8	.5	.3	.5	.5017	6
8	.4	.2	.9	.3	.3984	10
9	.2	.7	.6	.5	.4633	9
10	.5	.4	.3	.8	.4752	8
11	.1	.1	.9	.9	.3450	12
12	.6	0	.4	1	.1126	14.5
13	.9	.8	0	.9	.1464	13
14	.3	.4	.2	.5	.3353	11
15	.4	1	.3	.6	.5308	5

A bar graph was constructed to represent each case and four Applied Psychological Services' scientific staff members were asked to rank the cases in decreasing order of overall effectiveness, assuming equal weights for all components. Examples of the bar graph stimuli are presented in Figure 1.

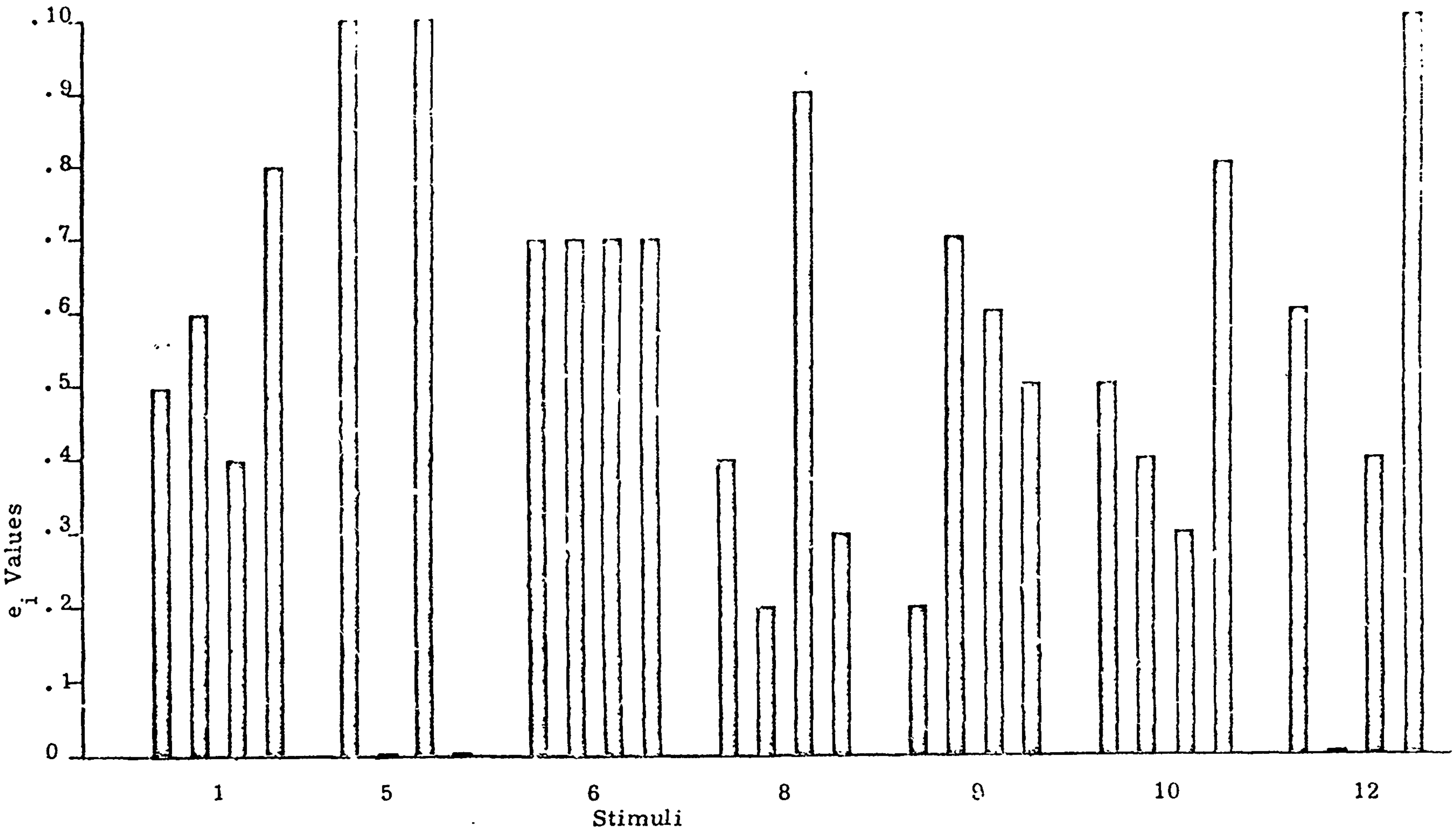

Figure C-1. Sample stimuli for comparing judgmental and E value results.

Rank order correlation coefficients (Rho) were calculated between E and each subject's ranking. The results are presented in Table 2.

Table 2

Rank Order Correlation between Subjective Rankings and E Statistic

	Subject 1	Subject 2	Subject 3	Subject 4	Overall
E	.988	.992	.765	.881	.972

It can be seen that the agreement of E with one subject was practically perfect. E rankings agreed very well with a second subject, and the agreement with two subjects was fairly good. The correlation of the mean ranking across the four subjects with E was .972. Note that the probability of perfect agreement on the basis of chance alone is

$$\frac{1}{n!} = \frac{1}{15!} = 7.6 \times 10^{-13}.$$

One of the subjects repeated the ranking after a three-week time interval. The correlation between the original and the second ranking was .968. Nevertheless the correlations with E were .988 and .978.

In the absence of a knowledge of the values of the correlation coefficients, an assumption of $r_{ij} = .5$ might be made. For four components there are six correlation coefficients. Each coefficient contributes $(.5)^2$ to R, so $a = \frac{r_{12} \ldots + r}{{}_nC_2} = \frac{6(.25)}{6} = .25$, and $b = 1 - a = 1 - .25 = .75$. This means that the additive term is weighted .25 and the multiplicative term is weighted .75. This holds true for any number of components.

For the general case of $r_{ij} = r$,

$$a = r^2, \; b = 1 - r^2.$$